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Air Quality Monitoring on the Tongass National Forest

Methods and Baselines Using Lichens

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Linda H. Geiser, Chiska C. Derr, and Karen L. Dillman

USDA-Forest Service
Tongass National Forest/ Stikine Area
P.O. Box 309
Petersburg, Alaska 99833

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Linda H. Geiser
Ecologist
USDA Forest Service
Siuslaw National Forest
Corvallis, OR 97331

Chiska C. Derr
Ecologist/ Coop Ed.
USDA Forest Service
Chugach National Forest
Girdwood, AK 99587

Karen L. Dillman
Biological Technician
USDA Forest Service
Tongass National Forest
Petersburg, AK 99833

CONTENTS

List of Figures

SUMMARY

An air quality biomonitoring program for the Tongass National Forest was initiated to 1) establish baseline conditions, 2) develop sensitive, easily repeatable methods for continued monitoring and 3), provide methods and information to help Forest Supervisors meet Forest Service responsibilities described by the Forest Service Air Resource Handbook and the Clean Air Act.

Baseline conditions were described through 1) element analysis of 366 samples of four lichens common to the forests and muskegs of the Tongass National Forest (*Alectoria sarmentosa, Cladina rangiferina, Hypogymnia enteromorpha,* and *Lobaria oregana*), 2), a forest-wide inventory of the macrolichens and their habitat characteristics at 176 temporary and permanent standardized sites evenly distributed in clusters over the Tongass and more than 45 additional collecting areas, and 3), a quantitative community analysis of branch lichen abundance in two common old growth forested habitats: shorepine (*Pinus contorta*), and western hemlock (*Tsuga heterophylla*).

Baseline values for S, N, P, K, Ca, Mg, Al, Fe, Na, Mn, Zn, Cu, B, Pb, Ni, Cr, and Cd were established for the Tongass National Forest. The four lichen species had distinctly different baseline element ranges. Standard error averaged <3% of the mean for S, N, 3-5% for K, Zn, Cu, Ni, P, 6-10% for Ca, Al, Mn, Cu, B, Pb and 11-16% for Na, Fe, Cr, and Cd. Large differences between baseline and non-baseline values for these and remaining elements around a significant point source indicate the method is sensitive, especially for S and N. No significant latitudinal or longitudinal trends were detected and the established baseline values should be valid for all parts of the Tongass. With the exception of Ca, Mg, K and Mn, which may be enhanced by marine influences, all values were within expected background ranges for non-industrial locations and were comparable to or lower than values available from other national parks and forests.

The lichen inventory was the most comprehensive to date for southeastern Alaska. The lichen flora of the Forest was found to be diverse and healthy. Species sensitive to sulfur dioxide were widespread, even in the vicinity of towns and roads. 381 lichens, mainly macrolichens, representing 101 genera, were documented. The typical macrolichens of natural hardwood stands, coniferous forests, alpine areas, beach/forest edge habitats, areas of recent glacial recession, and their known sensitivities to SO_2 are described. Lichen species composition was greatly influenced by vegetative habitat type and similar lichens were found in similar vegetative habitats. Canopy cover and elevation were important factors in the distribution of some species but not others. Results of the community analysis of branch lichens from shorepine and western hemlock forests will be published under separate titles. Combining element analysis with presence/absence of expected species and community analysis of branch lichens should provide a sensitive tool for detecting changes in air quality in the future or around present point sources.

A preliminary test of methods was made around the community of Sitka. Tissue levels of S, P, Na, Cu, Ni and Cd were most enhanced and Ca and Mg levels were most reduced within the vicinity of the Alaska Pulp Corporation pulp mill. K, Zn, Cr, Al, Fe, B, and Pb appeared to be influenced primarily by activities along the roads and within the town of Sitka. Elevated levels of S, Mn, Cu, Pb, Ni and Cr were detected at the north end of the Sawmill Highway in the vicinity of the state ferry terminal. A classic example of lichen species zonation may exist around the mill. Species richness and abundance, greatly diminished at the source, increased progressively with distance over several miles. More work is needed to verify these preliminary results and to better define the sensitivities of southeastern Alaskan lichens. Recommendations for continued monitoring are made.

1. INTRODUCTION

1.1 Why an air quality monitoring program? Agency and legal directives.

1.11 The Clean Air Act

The United States Congress enacted the Clean Air Act (CAA) in 1970 and its amendments in 1977 and 1990 in response to an increased awareness of the nationwide consequences of air pollution and environmental degradation. Under the CAA, Congress authorized the U.S Environmental Protection Agency to establish National Ambient Air Quality Standards (NAAQS) to protect the public health and welfare, and to administer Prevention of Significant Deterioration (PSD) permits for major new or modified pollution sources to prevent adverse impact in clean air regions of the country. Under the CAA, it is the responsibility of the Federal Land Manager, specifically the Regional Forester for Alaskan national forests, to monitor the effects of air pollution on the national forests and to affirmatively protect these resources.[1]

In 1977, Wildernesses larger than five thousand acres were designated as mandatory Class I areas, all other national forest lands were designated Class II. Of the 156 mandatory Class I areas in the nation, 88 are managed by the USDA's Forest Service. The resources on these federal lands are to be carefully and stringently protected and very little or no deterioration is permitted. Federal Land Managers of these areas are required to participate in the PSD permit process. All of the 20 Wildernesses of the Tongass National Forest, more than 5.7 million acres, have Class II status because they were established after 1977. Class II status does not specifically address resource protection and allows greater air pollution increments. Class I and II increments, the NAAQS, the definition of Air Quality Related Values and a descriptions of pollutants and sources are listed in the expired 1987 interim directive Forest Service Handbook on Air Resources Management (FSH 2509.19) and the Forest Service Manual (FSM 2580).

The Forest Service can protect Class II lands from air pollution by participating in the PSD process to ensure that air quality does not deteriorate beyond class II increments and that the best available pollution control technology is used on new sources.[2] Forest service personnel must be able to independently evaluate

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[1] Some of the specific responsibilities of the Federal Land Manager designated by the Clean Air Act are to:
a. Provide regional, station and area leadership and direction in air resource matters affecting lands under their jurisdiction. Consider present and potential effects on air quality related values (AQRV) in planning and implementing all resource and management activities.
b. Monitor the effects of air pollution, including atmospheric deposition, on Forest resources. This includes monitoring that will
   i. obtain useful data describing the air resource to support other Forest Service management activities such as smoke management, resource management and reclamation activities,
   ii. determine air resource impacts to and/or adverse effects on National Forest resources due to outside generated emission sources,
   iii. develop baseline data for modeling potential impacts from proposed new emission sources,
   iv. support multi-agency monitoring programs where it is in the national interest. Monitoring will be conducted in coordination with other data use groups when feasible.

[2] Under the Clean Air Act, any new major source of pollution or a modification of an existing source must meet the federal Prevention of Significant Deterioration (PSD) regulations in attainment areas for the pollutants(s) in question. The broad goal of the PSD program is to

proposals and effects, rather than merely echo the assessment of either the proponent or the regulatory agency. In Alaska, PSD permitting is administered by the designee of the Environmental Protection Agency-- the state Department of Environmental Conservation in Juneau. The Federal Land Manager's responsibility was included in the law to provide consultation to the permitting authority by knowledgeable and responsible land managers (expired interim FSH 2509.19).

1.12. USFS Air Resource Management policy

Within the US Forest Service, the Air Resources Management (ARM) program addresses issues of air quality. Although ARM originated as a PSD Class I area protection program, Class I areas comprise only 8% of the National Forest System. As air quality concerns over entire Forests have deepened, the ARM program has become more comprehensive. The value of understanding the air resource and the effect of air pollution on other resources is now as much to accomplish good integrated ecosystem management as it is to carry out the PSD requirements of the CAA . The Chief's policy is that air is a fundamental resource and shall be managed as other Forest resources such as soil and water. The ARM program is described in detail by agency documents including the Forest Service Air Resources Handbook (FSH 2509.19 Expired Interim Directive No. 1., and subsequent updates), the Forest Service Manual (2580) and individual Forest Plans.

To underscore the fundamental tenants of the US Forest Service ARM program, an agency framework document was prepared and approved in 1988 (USFS, 1988). One of its three basic elements is the protection of Class II areas by:

a. Determining locations for high pollutant concentrations and areas of probable adverse effects using existing emission data, air quality monitoring, personal observation, modeling, and professional consultation.
b. Determining current condition of Forest resources in these areas.
c. Establishing monitoring sites throughout the areas.
d. Orienting air regulatory personnel with condition, trends and significance of findings.
e. Training specialists and managers on operations and management methods.

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prevent significant air quality deterioration in areas of the country that are cleaner than the NAAQS while at the same time establishing suitable margins for industrial, commercial and residential growth. In a PSD permit application, the following major elements must be addressed:

a. background and overview,
b. process and best available control technology (BACT),
c. ambient air quality analyses,
d. meteorological monitoring and climate,
e. discussion of models used,
f. air quality impact assessment: emission inventory used, climate and meteorology synopsis, modeling results, Class I area impacts, Class II area impacts, NAAQS assessment. Neither Class II standards nor NAAQS may be exceeded on any national forest,
g. additional impact analyses effect of secondary growth, effects on vegetation and soils in Class II areas and visibility effects in Class II areas,
h. air quality related values (AQRV) impact assessment,
i. references.

1.13. Other federal mandates

U.S. Forest Service policies for the management and protection of air are founded in law. The Forest Service is required to preserve and protect the air resource under the mandates of the:

a. Forest and Rangeland Renewable Resources Planning Act of 1974, which requires the recognition of the fundamental need to "protect and, where appropriate, improve the quality of the soil, water and air resources".

b. The Federal Land Management Policy Act of 1976, which declares it the "policy of the US that the national interest will be best realized if the public lands and their resources are periodically and systematically inventoried in a manner that will protect the quality of scientific, scenic, historical, ecological and environmental, air and atmospheric, water resources and archeological values...".

c. State Implementation Plans (SIP). SIP is a document prepared by the State and required by the CAA. It is the contract between EPA and each State for attaining and maintaining acceptable air quality in the State. From a regulatory and protection perspective, the Forest Service can be very influential in the preparation of the State Implementation Plans. Such protection can go well beyond what would be required for the protection of Class I areas.

d. National Environmental Policy Act (NEPA) of 1976. Air is an issue common to all NEPA actions and many special use permits.

e. The Wilderness Act, the Farm Bill, the Organic Act of 1897, the Multiple Use-Sustained Yield Act and NFMA all mandate Forest Service roles in the protection of Forest health and ecosystems, of which air is an intrinsic element.

f. Agenda 21, the document signed by our country in 1992 at the United Nations Conference on Environment and Development in Rio de Janeiro, Brazil, places a high value on understanding ecosystems, including the atmospheric and climatological components.

In summary, if air pollution is affecting national forest lands, including Class II lands, Federal Land Managers have a responsibility to be able to detect it, define it, and speak up about it.

1.14. How can Forest Service land managers meet air resource management responsibilities in the Alaska Region ?

The first step is to establish an ARM program. This is described in the FSH 2509.19 and involves establishing the goals and objectives of the air program for individual Forests, including specific contents of the Forest Plan, program quality control, work load analyses, training, budgeting and plans for cooperation with other agencies and interest groups. Several regions have held workshops to define AQRV's, how they will be measured, what the concern levels will be, and what actions the Forest Service will take should these levels be realized (Haddow et al., 1992; Peterson et al., 1992; Adams et al., 1991). The next step is to build a management strategy, perhaps as part of the Forest Plan, followed by the development of monitoring plans.

Implementation of monitoring

Since the legally allowable pollutant levels are described as ambient atmospheric concentrations, one monitoring method involves instrument determinations of the air and deposition (wet and dry) composition. In theory, a single instrumented monitor may provide good baseline data for a very large area with only isolated point sources. In practice, maintenance of continuous monitoring instrumentation is expensive and in southeastern Alaska, the rough topography necessitates the use of several monitors to make accurate assessments over impacted areas of even limited size. Given these considerations, biomonitoring (ideally in combination with instrument monitoring) offers an economical approach which can provide a sensitive overview of air quality, detect fairly small changes in air quality geographically or over time, and identify areas which might need instrument monitoring. Moreover, lichen studies have the advantage of translating pollutant concentration numbers to tangible effects on biological systems. This report describes the current monitoring program for the Tongass National Forest using lichen biomonitors to 1), establish baseline element concentrations in lichens for the Forest, 2), describe the lichens associated with the dominant vegetative habitat types under natural conditions and 3), assess regional and local air quality changes.

1.2 Lichens and Air Quality

1.21 Where have lichens been used to monitor air quality?

Many studies have used lichens as indicators of changes in air quality and the literature now encompasses over two thousand publications worldwide. The 1988 publication, Lichens, Bryophytes and Air Quality (1988), provides an excellent overview of the current use of lichens as biomonitors of the environment. A continuing series in the scientific journal, The Lichenologist, reviews the most recent literature on the subject (compiled by Hawksworth to 1974, later by Henderson). The National Park Service (NPS) has had a national program of air quality biomonitoring using lichens since the early 1980's, coordinated by the Air Quality Division in Denver, resulting in a host of baseline and impact assessment reports (Christiano and Scruggs, 1985; Denison, 1987; Crock et al., 1992; Gough et al., 1988; Gough and Jackson, 1988; Lawrey and Hale, 1988; McCune, 1987; Rhoades, 1988; Wetmore, 1981, 1983, 1985,1987, 1988, 1989; Wilson 1986). Forest Service studies

utilizing lichen biomonitoring methodology have also become numerous in the past five years (Hale, 1982; Jackson, 1991; Lawrey, 1992; Lawrey and Hale, 1988; Neel, 1988; St. Clair, 1987, 1989, 1990, 1991; Ryan 1990a, b, c). Recently, the USFS and NPS jointly sponsored a workshop to produce a manual (Huckaby et al., 1993) standardizing lichen air quality biomonitoring techniques within the two agencies. Experimental methods and analytical instrumentation continue to become more refined and sensitive. In Europe, good historic records, current lichen chemistry data, and the presence of numerous instrumented monitors has enabled the production of accurate maps of ambient gaseous and toxic metal pollution concentrations (e.g. Herzig, 1989, 1988; Farkas, 1985; Van Dobben, 1992; Blum and Tjutjunnik ,1992; Bargagli et al., 1992; Diamantopoulos et al., 1992).

1.22 How does lichen biomonitoring work?

Structural rather than physiological differences appear to increase the sensitivity of lichens to air pollution compared to vascular plants (Richardson and Puckett, 1973). Lichens are composite organisms consisting of a fungus and an alga or blue-green bacterium living together in a symbiotic arrangement. About 1/4 of all known fungi are lichenized (15-20 thousand lichen species) (Vitt et al., 1988). Lichens are unprotected by bark or cuticle and have neither roots nor vascular system. They absorb atmospheric moisture, gases, and other components directly through the outer layers of their thalli (plant-like bodies without true roots, stems or leaves) and are adapted for efficiently taking up and conserving atmospheric moisture and its contents. Mosses, and at least some lichens, can accumulate 100-1000 times more sulfur than vascular plants under the same conditions (Winner et al., 1988). The large, convoluted surface of most lichens also make them good traps for dry deposition and particulates (Nash and Gries, 1991) which can remain on the surface, be exchanged on cell wall surfaces, or absorbed into the cytoplasm. As lichens lose moisture through evaporation, they concentrate elements and compounds from the surrounding environment. Element content can be reduced through leaching of living thalli or death and decay of older parts as ambient air concentrations decrease. Because lichens accumulate chemical elements, radioactivity and organic compounds in amounts correlating to average atmospheric concentrations, they are good summarizers of the environmental conditions in which they are growing.

Different lichen species respond differently to increasing levels of atmospheric pollutants, ranging from relative resistance to high sensitivity. Some are damaged or killed by annual average levels of sulfur dioxide as low as 13 $\mu g/m^3$, by nitrogen oxides at 3834-7668 $\mu g/m^3$, or by other strongly oxidizing compounds such as ozone. Other lichens are less sensitive and a few can tolerate levels of sulfur dioxide over 300 $\mu g/m^3$ (Wetmore, 1983). (The Class II allowable increment for the annual average concentrations of this pollutant is 20 $\mu g/m^3$.) The first indications of damage are inhibition of nitrogen fixation, increased electrolyte leakage, decreased photosynthesis and respiration followed by discoloration and death of the algae (Fields, 1988), and finally, the lichen. More resistant species tolerate regions with higher concentrations of these pollutants, but may exhibit changes in internal and/or external morphology (Nash and Gries, 1991; Will-Wolf, 1980b). The distinction

between sensitivity and accumulation is important. Lichens are relatively insensitive to many pollutants which they accumulate by dry or wet deposition, e.g. radioactivity (Biazarov et al., 1990), some metals (Nieboer et al., 1978; Nash and Gries, 1991), and organic compounds (Carlberg et al., 1983; Villeneuve and Holm, 1984; Bacci et al., 1986; Villeneuve et al., 1987).

There are two main approaches to lichen biomonitoring: 1) element analysis of lichen tissue, and 2) mapping species presence and cover (Wetmore, 1988; Will-Wolf, 1988). Element analysis can detect gradual changes in tissue levels before conditions become lethal and can be a more sensitive method than species mapping. The presence of specific anthropogenic elements in lichen thalli offers direct evidence of their presence in the air and the tissue concentrations can be compared to background values in the literature, or to baseline studies, to determine whether they are elevated. If tissue data can be calibrated with instrument data, lichens can be used to estimate annual average ambient levels, especially for SO_2 and metals.

By studying the lichens present in an area with reference to their sensitivities to sulfur dioxide, a preliminary indication can be obtained for the air quality of an area. If many or all of the more sensitive species are absent from an area where they would be expected to occur, there is a high probability that the air quality has been degraded. If all of the expected sensitive species are present, sulfur dioxide levels can be expected to have little biological impact on other organisms as well. Cautions when using this method exclusively (Denison, 1987): 1) lichen community dynamics are complex and a missing species can also be due to gradual climatological and environmental changes during natural succession, and 2) variation in the skill and meticulousness of the individual researchers who measure and identify the lichens can affect results as much as pollution effects. The most accurate results from this method are achieved where historical records (Wetmore, 1988) and a good quality control/quality assurance program to assess and minimize observer error are available (Smith et al., 1993). In the Tongass National Forest program, both element analysis and species inventory methods have been utilized.

1.3 The Tongass National Forest

The Tongass National Forest occupies a narrow land area between 54-60^o N latitude and 140-130^o W longitude, bordered on the east by Canada's British Columbia and on the west by the Pacific Ocean. Much of the land mass is dominated by an intricate system of fjords and mountainous islands, the Alexander Archipelago. The six largest islands are Prince of Wales, Baranof, Chichagof, Admiralty, Revillagigedo and Kupreanof and their summits range from 760-1070 m. (2,500 to 3,500 ft.) in elevation. In contrast, the rugged mainland strip has peaks as high as 3050 m (10,000 ft). The ten major rivers of the region originate in Canada. The Stikine River has the largest drainage area, followed by the Alsek, Taku and Chilkat Rivers. In the extreme north, the Yakutat district consists of a low, hummocky, irregular, mainland coastal plain less than 70 m (220 ft.) in elevation. The 6.8 million ha.

(16.8 million acre) Tongass National Forest averages 190 km (120 miles) wide, 900 km (600 miles) long, and encompasses most of southeastern Alaska (**Fig. 1**).

Cool, moist, maritime conditions produce a lush forest, which is an extension of the rain-belt forest of the Pacific Northwest. The forest is interrupted by muskegs (peat lands), glacial outwash plains, and marsh-lands in river valleys and deltas. Timberline varies between 610-915 m. (2000-3000 ft.) and forests are commercially harvested up to 460 m. (1500 ft.). The predominant trees are western hemlock (*Tsuga heterophylla*) (75%), Sitka spruce (*Picea sitchensis*) (20%), red and yellow cedars (*Thuja plicata* and *Chamaecyparis nootkatensis*), mountain hemlock (*Tsuga mertensiana*), cottonwood (*Populus trichocarpa*), and red alder (*Alnus rubra*). Forest soils on sloping terrain are primarily spodosols. Flat areas usually become "muskegs" (peatlands) and in these areas the soil is strongly acidic, almost entirely organic and continually saturated. No permafrost exists at forested elevations. High elevations support alpine vegetation, and above this one finds rock, ice and snow. A checklist of vascular plants lists 1014 species (Stensvold nee Muller, 1982). Ian Worley's (1972) inventory reported 533 bryophytes. This report lists 381 lichens and several hundred more are presumed to exist.

1.4 Regional meteorological patterns and pollutants

Due to the inland water passages and proximity to the north Pacific Ocean, most of southeastern Alaska, including the Tongass National Forest, has a marine climate. This means small temperature variations, high humidity, high precipitation, considerable cloudiness, and, at sea level, little freezing weather. An exception is Skagway in the northeast which lies in a transition zone between marine and continental climates. Although there are many meteorological stations, all are near sea level and only a few have operated on a continuous, long term basis. The endless variety of peaks, valleys, ridges, and broad slopes, each presenting a different aspect to the wind, creates large climatic variation over short distances. The following subsections were compiled using information from the National Weather Service in Juneau, the Alaska State Climate Center at the University of Alaska in Anchorage, and the Southeast Alaska Regional Guide (Selkregg, 1976).

1.41 Temperatures

Temperatures at sea-level range from 4 to 18 C (40 to 65^{o} F) in summer and from -8 to -4 C (17 to 43^{o} F) in winter. Average temperatures decrease with elevation. In summer, cooler temperatures occur on or near the coasts; warmer temperatures farther inland. The reverse is true in winter and warmer temperatures along the coasts reflect the strong maritime influence. Extreme temperatures in both winter and summer occur when air masses move across the mountains from Canada, bringing clear skies and continental air. The Alaska current originates in the tropical waters along the equator and flows northward by southeastern Alaska modifying cold air outbreaks. Therefore average sea level air temperatures in southeastern Alaska compare favorably with those several hundred miles to the south.

1.42 Precipitation, Wind and Storm Patterns

The average annual precipitation is well over 2540 mm (100") in much of southeastern Alaska. The actual amount of annual precipitation depends on global weather patterns, local topography and air temperature. Surface winds average 11-16 km/hr (7-10 mph) during summer months, increasing to 16-24 km/hr (10-15 mph) during the winter. A discontinuous belt of low pressure occurs over a large area in the north Pacific Ocean, including southeastern Alaska. Storms bring moist, seaborne air which cools and condenses as it is intercepted and forced upwards by the steep mountain slopes. Storms and moderate to heavy precipitation occur year round although the low pressure areas are most developed in winter. In summer, when the land becomes warmer than the water, the low pressure areas diminish. Snow occurs frequently in all areas during winter, but it usually melts after a few days at lower elevations in the southern third of the Forest. Accumulations of 1520 mm (60") or more are not uncommon in the northern two-thirds of the Forest. In the mountains 5100-1000 mm (200-400") of snow accumulates each year, helping to perpetuate the ice fields and glaciers.

Only the outer Pacific coast conforms strictly to the global pressure patterns. Local topography usually causes large changes in wind speed and direction. For example, the mountains along the Alaska-Canada border form a barrier to most storms from either direction. But in winter, under certain conditions of temperature and pressure gradient, cold air can cascade out of Canada through passes and channels such as Glacier Bay, Lynn Canal, Taku Inlet, the Stikine River valley and the Unuk River valley at wind speeds of 160 km/h (100 mph) or more . In addition, if the cold air mass over Canada is deep enough, the air will pour out over some of the lower elevations including the Juneau Ice Field, Tracy and Endicott Arms and the Whiting River valley, all of which have glaciers or ice fields as sources.

1.43 Solar radiation and heat

The amount of heat energy that reaches the earth's surface in southeastern Alaska is diminished due to energy absorption primarily by water vapor but also by aerosols and certain gases. The extensive cloud cover also reflects heat energy. In winter, low sun angles cause more energy to be absorbed by the atmosphere before it reaches land surfaces and distribute the rays over a larger area, reducing energy

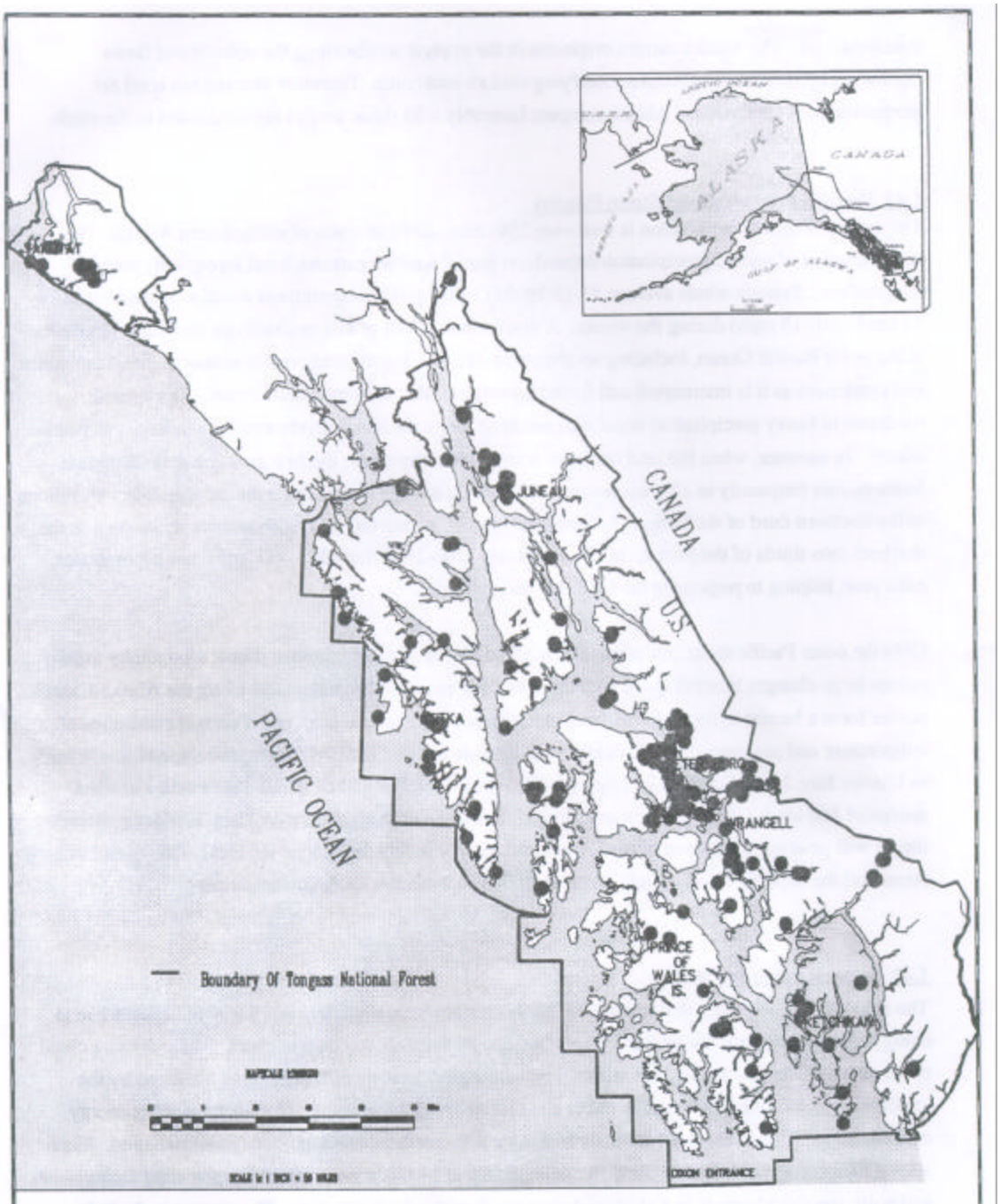


Figure 1. Air quality monitoring locations on the Tongass National Forest.

concentration. This is balanced annually by longer summer days which produce more radiation. Mean annual temperature and climate can differ dramatically at two locations a short distance apart facing south and north since the latter is in a shadow during much of the day's sunshine. The change in daylight length from summer to winter is not as great as in the rest of Alaska. Shortest winter days range from 6 hours at Yakutat to 7 hours, 10 minutes at Annette Island, south of Ketchikan.

1.44 Regional Air Quality

Fog is by far the principal cause of reduced visibility in southeastern Alaska. Fog is an obstruction to vision up to 21 days per month in Yakutat, 7 days in the Juneau vicinity and 13 days in the Annette Island vicinity. On rare occasions, forest fires in British Columbia or the Yukon Territory have contributed to regional haze during summer months, but generally smoke and haze have a negligible impact. An exception is the Mendenhall Valley, which has been classified as a non-attainment area for particulate matter smaller than 10 µm (PM-10).

There are no monitors of visibility or of specific pollutants in non-impacted areas, thus baseline data for common air pollutants such as sulfur dioxide (SO_2), nitrous oxides (NO_x), peroxyacetylnitrate (PAN) or ozone (O_3) are unavailable for southeastern Alaska. On the other hand, because wind and storms originate in the north central Pacific Ocean or the Canadian interior, there are no large centers of industry directly affecting the Forest. In addition, the frequent rains tend to cleanse the air. To model Prevention of Significant Deterioration (PSD) increment consumption permitted by the CAA, baseline concentration values are established when owners of emission sources apply for PSD permits. In southeastern Alaska, default values have been used for ambient impact modeling: 0 $\mu g/m^3$ for SO_2, 0 $\mu g/m^3$ of $N0_x$ and 50 $\mu g/m^3$ for ozone (Baumgartner, 1993). As no major source of particulate matter has been constructed in southeastern Alaska since 1975, particulate matter baselines have not been established.

Air pollution in southeastern Alaska arises from area sources such as wood stoves and dirt roads, and can be exacerbated by a temperature inversion. Calm wind conditions can also contribute to serious pollution problems. Terrain, particularly mountains, limits the atmospheric dispersal and causes pollutants to concentrate. Such conditions exist in the Mendenhall Valley, Ward Creek valley in Ketchikan and the Silver Bay area in Sitka. Most of these areas are partly within the Tongass National Forest boundaries.

1.5 Point sources of air pollution in Southeast Alaska

Point sources are usually associated with population centers. The largest community is Juneau (pop. 26,751) the state's capital, followed by Ketchikan (8,252), Sitka (8,588), Petersburg (3,207) and Wrangell (2,481) (U.S. Census Bureau, 1992). Community development is hampered by steep topography and most settlements are located on narrow benches on the seacoast. Land surface transportation, and thus vehicle

emissions, is very limited, and the Alaska Marine Highway System and air travel provide most of the access in and through this region.

Southeast Alaska facilities holding air quality control permits from the Alaska Dept. of Environmental Conservation are listed in **Fig. 2**.

Mendenhall Valley

Juneau's Mendenhall Valley is a non-attainment area for PM-10, i.e. it does not meet minimum human-based health standards for particulate matter <10 µm. The main cause of the fine particulate matter is dust from the large number of unpaved roads and wood smoke from home heating. The non-attainment status of this area is addressed in the State Implementation Plans amendment which was adopted by the EPA in December, 1993. The non-compliance area includes National Forest land.

Figure 2. Facilities with state air quality control permits in Southeast Alaska.

Facility	Permit #	Location	Emissions Source
AEL&P Auke Bay	8911-AA009	Juneau	diesel electric power plant
AEL&P Lemon Cr.	8811-AA003	Juneau	diesel electric power plant
Alaska Pulp Corporation	9112-AA005	Sitka	pulp mill-- NOT OPERATING
Alaska Pulp Corporation	9013-AA008	Wrangell	sawmill
Assoc. Sand& Gravel	9112-AA010	Sitka	asphalt plant
Channel Sanitation	9211-AA007	Juneau	2 municipal waste incinerators
Chilkoot Alaska Lumber	expired	Haines	sawmill- NOT OPERATING
CBJ J-D Treatment Plant	9011-AA004	Juneau	sewage sludge incinerator
City of Sitka Incinerator	8812-AA008	Sitka	2 municipal waste/sludge incinerators
Coeur-Alaska Kensington Ventures	9111-AA009	Juneau	diesel/combustion turbine power plant and gold processing mill
HL&P	9011-AA009	Haines	diesel power plant
Kennecott Green's Ck Mill	9111-AA001	Admiralty Island	diesel power plant & silver/lead/zinc mill-- NOT OPERATING
Kennecott Green's Ck Hawk Inlet	9111-AA006	Admiralty Island	diesel power plant-- NOT OPERATING
Ketchikan Pulp Co.	8913-AA008	Ketchikan	pulp mill
Klawock Timber Alaska, Inc.	8913-AA007	Klawock	sawmill-- NOT OPERATING
Petersburg MP&L	9212-AA003	Petersburg	diesel power plant
Red Samm Stansteel	9911-AA001	Juneau	asphalt plant
Red Samm Stansteel	8931-AA010	Petersburg	asphalt plant
South Coast Stansteel	9013-AA003	Ketchikan	asphalt plant
THREA Hoonah Plant	9111-AA008	Hoonah	diesel power plant
Wilder Construction	9213-AA006	Prince of Wales Is.	asphalt plant

APC Sitka and KPC Ketchikan

The Alaska Pulp Corporation (APC) recently closed pulp mill in Sitka and the Ketchikan Pulp Corporation (KPC) pulp mill in Ketchikan have been the largest stationary point sources of volatile organochlorines (VOC's), sulfur-dioxide and particulate matter. They are both magnesium-based sulfite pulp mills producing an annual average of 760 tons of air-dried, unbleached pulp per day. There are multiple sources of SO_2 emissions at the mills, including digester tanks, washer vents, storage tanks, digester relief systems,

evaporators, wood waste power boilers and chemical recovery boilers (ADEC, 1993). There was one SO_2 monitoring station within 0.25 miles of the APC Sitka mill on an elevated bench next to Heart Lake. This site was dismantled October, 1993. Typical periodic summary reports indicated that SO_2 levels were well within health-based 24 hour, 3 hour, and annual increments (ADEC, 1992; ENSR, 1992).

The pulping and chlorine bleaching processes create an array of over 1,000 chlorinated organic compounds, including extremely toxic carcinogens, mutagens and immunosuppressants such as dioxins, furans and polychlorinated benzenes (PCBs). None or few of these compounds occur in nature. Only about one third of these compounds are known chemically, and even fewer have been assessed for their environmental toxicity. About 2 % of the organochlorines formed during bleaching will remain in the pulp, the rest are released as waste products (Bonsor et al., 1988). Total organochlorine release has been calculated from AOX (total adsorbable organic halide) tests of mill effluents, from self-reported data released to the EPA, at over 18 million and 27 million pounds per year by the Ketchikan and Sitka mills respectively (Greenpeace, 1990). Fly ash from the APC mill in Sitka has in the past contained dioxin levels from 70-140 ng/g (parts per billion) (Miille, 1990). Dioxins are some of the most toxic chemicals known-- one isomer, TCCD, has a lethal OD_{50} (dose which is lethal to 50% of the animals) of 10 ng/kg body weight (Freedman, 1989). The fly ash was released into the air until electrostatic precipitators were installed in 1989. For a short period ending in 1990, fly ash captured by the precipitators was, after utilization as a slurry neutralizer, dumped directly into Silver Bay (Alexakos, 1990). From 1991 until the recent closure of the mill, the fly ash was bagged in reinforced nylon, solidified by dampening, and buried in the lined landfill of Sitka.

The production of organochlorines could be exacerbated by the transportation of logs to the mill through salt water. The salt soaked bark and outer wood are peeled from the logs before pulping and burned for fuel, releasing hydrochloric acid and organochlorines which formed as products of incomplete combustion. Many of these compounds have an affinity for particulate matter and are trapped by air pollution control devices and buried in the city landfills. The remainder may be released into the air and water. Most of the dioxins and furans are contained within fly ash and not released into the air (Baumgartner, 1993), but the release of other toxic organochlorines is not well understood. According to self-reports to the EPA National Air Toxics Information Clearinghouse (1989), significant amounts of at least some chlorinated compounds are released into the air. In 1987, the Sitka and Ketchikan mills emitted 360,000 and 340,000 kg of chloroform, respectively, two of the highest emission levels in the Clearinghouse national database. To date, questions of release, deposition, and terrestrial or marine bioaccumulation of organochlorines in the National Forest or communities surrounding the mills remain unanswered.

The mill at Sitka was issued a new permit in 1993 which was challenged in court by the Sitka Conservation Society. The adjudication process decided in favor of the Sitka Conservation Society and tighter restrictions were approved. APC was directed to carry out a vegetation study to account for apparent damage to trees and other flora on hillsides near the facility as well as the probable cause of widespread insect damage on

vegetation in the vicinity of the facility. A draft report was released in 1992 and a final report issued March 1993 (ENSR, 1992). These reports did not adequately explain sulfur dioxide toxicity symptoms observed in the vegetation in the vicinity of the mill. Since the first draft of this report, APC has closed the mill in Sitka.

Title III of the 1990 amendments to the Clean Air Act specify for the first time a number of air toxics (189 specific pollutants) which must be regulated by EPA within strict deadlines specified by Congress. These include organic chemicals and pesticides, metals, radionuclides, and mineral fibers. Regulations being developed under Title III of the CAA, will affect pulp mills and municipal incinerators. EPA proposed pulp mill standards in November 1993 for emissions of hazardous air pollutants.

Kennecott Green's Creek Mining Company

Kennecott Green's Creek operates a silver, lead and zinc mine within the Admiralty Island National Monument. To reduce air quality impacts, they use a light grade of diesel fuel, with a sulfur content normally between 0.1-0.3%, and the average annual production of 35 tons of SO_2 should not be of great concern. The more serious pollutants are NO_x compounds, which are produced at annual rates of 400-500 tons/year. This company was planning an expansion which would have emitted an additional 250 tons of NO_x/year but has shut down mining operations pending improvements in the world market for metals (Baumgartner, personal communication).

Cruise ships

A recent and growing source of pollution is from the large cruise ships which travel the inside passage and dock at the cities with deep harbors, most notably Juneau and Ketchikan. These ships each have 3-4 heavy fuel (2-4% sulfur content) boilers or propulsion engines and produce sulfur dioxide at rates exceeding all other permitted sources combined while cruising and in port (Baumgartner, personal communication). The State currently applies a visible emission standard for the vessels, but does not regulate sulfur dioxide emissions.

Power Plants

The diesel-electric generating facilities located in Juneau, Ketchikan, Sitka, Petersburg and Wrangell have been "grandfathered" from operating permit requirements (unless modified) during the past 15 years. If they were used continuously they could impact air resources. However, hydro-electric projects provide power to these communities, and these substations are now used only as standby or backup facilities to provide power during interruptions and periods of high demand (Baumgartner, 1993).

Sawmills

There are large sawmills at Haines, Klawock, Ketchikan and Wrangell. Only the Wrangell and Ketchikan mills are currently operating. The Ketchikan mill obtains power and steam from the KPC Ketchikan pulp mill, so has no source of air contamination on-site. The other mills burn lighter grades of fuel and woodwaste in power boilers. All sites are considered to be in compliance or unclassified for health based ambient standards and the main pollutant of concern to the State is particulate matter. There is a sawmill on the Annette Island

Indian reservation with wood waste incinerators but the State has no jurisdiction over Indian Reservations for the purpose of air quality control (Baumgartner, personal communication.

Asphalt plants

There are several mobile asphalt plants, and two permanent asphalt plants at Ketchikan and Juneau.

Other Mines

Additional mines may be opened in the future: a large molybdenum mine inside the Misty Fjords National Monument and many smaller gold mine operations in the Juneau vicinity. The main pollutants expected from these operations would be NO_X and particulate matter.

Other non-permitted pollution sources

Other point sources of pollution exist from the incineration of city garbage at Juneau, Sitka, and Ketchikan, from the operation of motorized vehicles and vessels, and from wood smoke from heating of private homes during the winter.

1.6 Program Objectives

The primary objectives of the Tongass National Forest Air Quality Biomonitoring Program are to:

1. Frame and present air quality monitoring information in a form that the Forest Supervisors can most effectively use to better manage air resources on the Tongass National Forest.

2. Help Forest Supervisors meet responsibilities for Air Resource Management described in the Forest Service Handbook (FSH 2509.19) and the Clean Air Act .

3. Establish sensitive, economical methods to define, map the area of deposition, and estimate the concentration of air pollutants on the Forest. Understanding the nature and extent of air quality impacts is critical to the management and protection of air as a resource, and as an essential component of the Forest ecosystem.

4. Provide information useful to Pacific coast, national and international scientific networks monitoring air quality on a global basis by publishing the results of present and future monitoring results and methodology in government reports and scientific journals, and exchanging information with other researchers involved in such programs.

To meet these objectives, a program has been designed which uses lichens as biomonitors of air quality conditions. The program has three components: tissue analysis, inventory and community analysis.

2.0 METHODS

2.1 Plots: selection and description

Data for this study was collected during the summers of 1989-1992 . Eighty permanent and 130 temporary 42' radius plots were established to sample the typical lichen communities and establish baseline concentrations of seventeen elements for four common lichen species. The permanent plots were established for long term monitoring of lichen chemistry and community composition. The plots were clustered in sixty locations distributed more or less evenly among the three administrative Areas (Chatham, Stikine and Ketchikan) of the Tongass National Forest . Most plots were in mature or old-growth forested habitats, including riparian areas. The remainder were in second growth stands, beaches, recently glaciated areas and alpine tundras.

Forested plots were chosen according to standard procedures used for the development of the Stikine Area plant association classifications (Pawuk and Kissinger, 1989). Plots were located entirely within a single plant association. Large stand openings, disturbed areas, and breaks in topography were generally avoided. Plot center was marked with plastic flagging at temporary plots and by pounding a 6 ft. fluorescent orange aluminum conduit pole 2 feet into the soil at permanent plots. Plot edges were flagged at four points, perpendicular through plot center. Non-forested temporary plots tended to be less homogeneous, but were otherwise established in the same manner.

Fig. 3 lists the variables recorded at each plot from 1990 through 1992. The 1989 plot cards were identical except non-lichen vegetation data was limited to percent canopy cover and identification of the plant association.

The date, names of all observers, general location and USGS quadrangle (15 min. series topographic), township, range and quarter section were recorded at each site. USDA-FS aerial photos or photocopies of them were marked with the location of permanent plots and the photo number was recorded on the data card. Elevation, percent slope and aspect were recorded from hand-held instruments. Landform was assessed from the USGS maps (See Pawuk, 1993 for landform designations). Soil drainage class was estimated by the vegetation observed on the plot and by plot slope.

Successional stage assignments are estimations. Generally, mature stands were large trees of even age, whereas old growth sites contained trees of all ages from sapling to standing old snags. Pole timber were trees greater than 5" in diameter and under 200 years old. Seedling/sapling was anything smaller than pole timber. Forb/shrub classifications lacked trees. All *Pinus contorta* associations were considered old-growth as they are rarely susceptible to blow down or fire and are not commercially harvested.

Figure 3. Field data card.

Tongass National Forest
DATA CARD

Data card #	
Plot #	
Date	Pool (%)
Observers	Landform
General location	Soil drainage
Quadrangle	Plant association
Township	Successional stage
Range	% canopy cover
Section	Ave. stand height (ft.)
Area	Ave. dbh (in.)
District	Ave. understory height (ft.)
Aerial photo #	Ave understory dbh (in.)
Elevation (ft.)	Ave. shrub height (ft.)
Slope (%)	% dead and down
Aspect	Ave. understory height (ft.)

Indicator Species:

Trees	% Overstory	% Understory
Chamaecyparis nootkatensis		
Picea sitchensis		
Pinus contorta		
Populus trichocarpa		
Thuja plicata		
Tsuga heterophylla		
Tsuga mertensiana		

Tall Shrubs	% Cover
Alnus rubra	
Alnus sinuata	
Cladothamnus pyrolaeflorus	
Menziesia ferruginea	
Oplopanax horridum	
Vaccinium spp.	

Low Shrubs
Cassiope mertensiana
Empetrum nigrum
Leutkea pectinata
Phyllodoce glanduliflora

Forbs And Grasses
Caltha biflora
Carex sitchensis
Circea alpina
Fauria crista-galli
Lysichitum americanum

Ferns
Dryopteris austriaca
Pteridium aquilinum

Other Vegetation	% Cover

Animal Signs/Sightings:

Herbarium#	Lichen Species	Abundance	Substrate

Notes:

Plot Location And Explanation Of Photos:

Visual canopy coverage estimates were made for both the overstory and the understory for each tree species. Canopy cover estimates were made by summing and averaging several estimates made by each observer from 5 or more points representative of the plot. Understory was defined as the trees overshadowed by taller trees. The height of one dominant tree was determined by triangulation using % slope to the top of the tree at least 35 horizontal meters away from the tree base or, where the overstory was under 20 m, by visual estimation. The heights of other overstory trees were visually estimated to the nearest 2 m using the measured tree as reference. The mean height of the living overstory and understory in the stand was estimated and recorded. In open grown *Pinus contorta* associations, overstory trees also had to be a minimum of 2.7 m. Diameter at breast height (dbh), or at the lowest height above pronounced bole swell, was measured to the nearest 2.5 cm for overstory and understory by measuring at least five representative trees and calculating an average.

Other data recorded were percent cover from dead and down logs and from permanent pools of water, and shrub height to the nearest 0.15 meter. The diameter of at least five typical overstory trees was measured to the nearest 2.5 cm and then averaged. Finally notes were made on any unusual features of the plot and any animal sightings or activity recognized.

Within plots, plants were identified to species when known. Percent cover of each species was estimated to the nearest one percent between one and ten percent cover, and in five percent cover classes thereafter. Percent cover of plants known to be indicators of forested plant associations (Pawuk and Kissinger, 1989) were always recorded. Records of other species were less thorough. Species less than 1% were recorded as a trace. Plant association was determined from the indicator plants using the keys of Pawuk and Kissinger (1993). Some associations outside the Stikine Area which did not fit this key were assigned associations using Ketchikan (DeMeo et al.) or Chatham plant association keys (Martin, 1989). Non-forested associations were classified according to Demeo (1988). Identification of trees and shrubs conforms to Viereck and Little (1972). Anderson's Flora of Alaska and Adjacent Parts of Canada (Welsh, 1972) was used to identify forbs, graminoids and ferns. No bryophyte data were collected.

2.2 Element Analysis: collection, preparation and laboratory analysis of lichen tissue

Four lichens were collected for tissue analysis*: Alectoria sarmentosa, Cladina rangiferina, Hypogymnia enteromorpha* and *Lobaria oregana*. All are common throughout the Tongass. Sometimes all four species were present in the plot area, but more often only 2-3 species were abundant enough to sample. All tissue collections were made outside the perimeter of the permanent plots. Enough lichen thallus for three laboratory repetitions of each species present was collected near each of 80 plots. The number of repetitions was chosen by a pre-experiment in 1989 in which up to five repetitions were analyzed per plot. Because variation within plots was smaller than variation between plots (possibly because 10-30 individuals normally comprised each repetition) the number of plots rather than repetitions was increased.

In shorepine muskegs, lichens were collected directly from tree branches and placed in acid-free paper packets made from 8.5 x 11" 100% cotton herbarium paper folded into a standard size herbarium packet. Three bulging packets of each species were created by collecting individual lichens from several to many trees per package. All packets were air dried the evening of collection. Later these became the three laboratory repetitions. *C. rangiferina* only grows on the ground and was collected by breaking off the thallus above the soil surface and placing in paper packets. *A. sarmentosa* was lifted from the branches and torn from its holdfasts. *H. enteromorpha* was carefully separated from the bark with a stainless steel knife blade. Collectors did not wear gloves.

In all other forested associations, lichens were collected from the litterfall and fallen branches. Only healthy, untrampled specimens were collected. *L. oregana* was collected from through-fall or gently torn from fallen branches. Healthy thallus fragments, free from rot, were placed directly in the paper packets as described above.

Between 1989 and 1990, a total of 278 lichen samples were collected and analyzed from 47 permanent plots. An additional 98 samples of *A. sarmentosa* from 33 *Pinus contorta* muskeg plots were collected in 1991 and 1992 and analyzed in 1992. All samples were hand cleaned to remove visible pieces of bark, grit and other foreign matter. Cleaned, air dried samples of one gram or more of each repetition were then placed in a 6 x 11 cm Kraft envelope, labeled, and mailed to the testing laboratory.

Laboratory analyses were made at the University of Minnesota Research Analytical Laboratory, Dept. of Soil Science. At the laboratory, samples were ground, stored in envelopes and re-dried to 65 C prior to analysis. The following analyses were made:

Sulfur: A 100-150 mg portion of each ground sample was analyzed for total sulfur by dry combustion followed by measurement of evolved sulfur dioxide on a LECO Sulfur Determinator by infra red absorption (Research Analytical Lab., 1992a). Standards used for sulfur were commercially prepared Peach leaves (Alpha Resources, Stevensville, MI), and NIST 1572 Citrus leaves.

Calcium, magnesium, sodium, potassium, phosphorus, iron, manganese, aluminum, copper, zinc, cadmium, chromium, nickel, lead and boron: These elements were determined simultaneously by inductively coupled plasma atomic emission spectrophotometry (ICP-AES) (Research Analytical Laboratory, 1993). For each sample, one gram of dried material was dry ashed in a 20 ml. high form quartz crucible at 485 C for 10-12 hours in a circulating air muffle furnace. Crucibles were covered during the ashing as a precaution against contamination. 5 ml. of 20% HCl was added to the ash. After 15 minutes, 5 ml of deionized water was added and the ash was allowed to settle for 3 hrs. The supernatant was decanted and transferred to 7 ml plastic disposable tubes for direct determination by ICP. The ICP standard was NIST 1575 Pine Needles.

Nitrogen: Total nitrogen was analyzed by a micro-Kjeldahl method (Research Analytical Laboratory, 1992b). The nitrogen standard was NIST 1575 Pine Needles.

Appropriate reference checks and analytical splits were run, including an "in-house" check of *A. sarmentosa* from a large batch collection made in 1989 on Mitkof Island. These checks and statistical analysis procedures are discussed in more detail in section 3.2. Results were recieved in a summary sheet from the laboratory as %S, %N and ppm (dry weight) of the remaining elements. Individual sample dilution factors and direct instrument readings for ICP results were also provided.

2.3 Lichen inventory

At all sites, a thorough survey was made of the macro-lichens growing on the forest floor, in the litterfall, and on trunks and branches of trees and shrubs visible without climbing. A list of species was made in the field and each species was given a general abundance rating on the data card according to the total number of times it was observed: 1 (once), 2 (2-5 times), 3 (6-15 times), 4 (16-40), 5 (over 40). For lichens which grow in colonies (e.g. *Cladonia*), the abundance rating reflected the number of colonies, not individuals. This method worked well for the larger, common macrolichens such as *Lobaria*, *Alectoria*, *Bryoria, Usnea, Peltigera, Platismatia* and *Sphaerophorus*, which are visible from a distance. For the smaller macrolichens and crustose specimens, and genera like *Cladonia*, in which many species are morphologically similar, it was only a rough estimate. For these lichens, the lower the abundance rating, the less certain the accuracy.

Although some lichens are readily recognizable, many cannot be identified in the field. All lichens whose taxonomy was uncertain were collected in paper packets, assigned a guess or descriptive name and rated for abundance on the data card. These packets were dried the same evening and stored.

Lichens collected in 1990 were identified at the Canadian Museum of Nature national lichen herbarium (CANL) in Ottawa, Ontario by Linda Geiser, Irwin Brodo and Pak Yau Wong. Taxonomic keys developed by Brodo for the Queen Charlotte Islands and by Trevor Goward for British Columbia, various monographs, and a combination of chemical spot tests and thin layer chromatography (TLC) were used. Identifications were checked against herbarium specimens from the Queen Charlottes and British Columbia, when available, and from other parts of the world for rare or unusual specimens. Much of the thin layer chromatography work and some identifications were performed by Pak Yau Wong. Lichens collected in 1989 and 1991, including all *Cladonia* and crustose species from those periods, and some 1992 collections, were identified at the University of Wisconsin at Madison by John Thomson of the Dept. of Botany, and Linda Geiser, referencing the herbarium (WISC) and Dr. Thomson's library. Identifications were compared to Thomson's collections from Alaska and to type specimens or exsicatti whenever possible. Micro-crystal tests were used in lieu of

TLC, mainly for the identification of *Cladonia* species. Additional genera from 1989 and 1991 were identified by Chiska Derr with the assistance of Bruce McCune at Oregon State University at Corvallis using chemical spot tests and the OSU herbarium and library. Selected *Hypogymnia* and *Heterodermia* specimens were verified by Trevor Goward of the University of British Columbia. Seventy five 1993 collections, mostly from alpine areas, were identified by Bruce Ryan at Arizona State University. Classification of all lichens conforms to the North American nomenclature described by Egan in 1987 and subsequent updates (1989, 1990, 1991).

2.4 Lichen community analysis

A simple community analysis was made of the relationship between three important environmental variables and the lichen species composition at any given plot:

2.41 Vegetation type relationships

The plot description and lichen survey database was sorted by the dominant vegetation types listed in **Fig. 4**. Within each of these communities, the percentage of plots in which each lichen species was found (presence/absence) was calculated. A lichen species list was created for each community with each species having a number from 0 (not found on any plots) to 100 (found on all plots). Statistics software (SYSTAT, 1992) was used to compare the species list for each community. A Pearson correlation matrix was produced to indicate the degree of similarity between lichen communities of the different vegetative habitats. A Bonferroni probability matrix was calculated to distinguish statistically different lichen species lists. The correlation matrix was used in a cluster analysis to produce a single linkage tree diagram joined by Euclidean distances and a multi-dimensional scaling analysis. Note the forested communities are differentiated to level IV as described by Viereck. Alpine habitats are differentiated to level I and early successional habitats to level III (Viereck et al., 1992).

2.42 Canopy cover relationships

A Pearson correlation matrix, a single linkage tree diagram, and a multi-dimensional scaling analysis were also created to look at effects of canopy cover. To do this,the percentage of plots in which each species occurred was calculated for each overstory % canopy cover range: 5-10, 11-20, 21-30, 35-40, 45-50, 55-60, 65-70, 75-80, 85-95. Only data from temporary and permanent coniferous forested plots were used in these calculations.

Figure 4. Dominant vegetation types of southeastern Alaska.

Vegetation Types (# of plots)	Acronym	Description

Western hemlock series (35) Western hemlock-Yellow Cedar series (6)	TSHE CHNO	Tall, old-growth forests, with generally high canopy cover on slopes.
Sitka spruce series (33) Sitka spruce-Alder series (15)	PISI ALDER	Tall, old-growth forests of nutrient rich riparian areas and beach edges.
Mixed conifer series (11)	MXDCON	Shorter, generally lower canopy cover, old growth forests on mild slopes, mainly low elevations
Mountain hemlock series (11)	TSME	Shorter, mainly high elevation forested old-growth areas (1000 to 2500 feet) and including all subalpine plots.
Shorepine muskegs (62)	PICO	Short, very low canopy cover forests in open, flat peat bogs.
Cottonwood series (14) Willow series (10)	POTR SALIX	Forests of frequently disturbed riparian areas with mineral soils.
Alpine habitats (8)	ALPINE	Exposed, treeless areas greater than 3,000 feet.
Early successional, moss and lichen dominated habitats (6)	MOSSLIC	Primarily sea level, rocky areas at the termini of retreating glaciers, or along the gravelly banks and floodplains of glacially fed rivers.

2.43 Elevation relationships

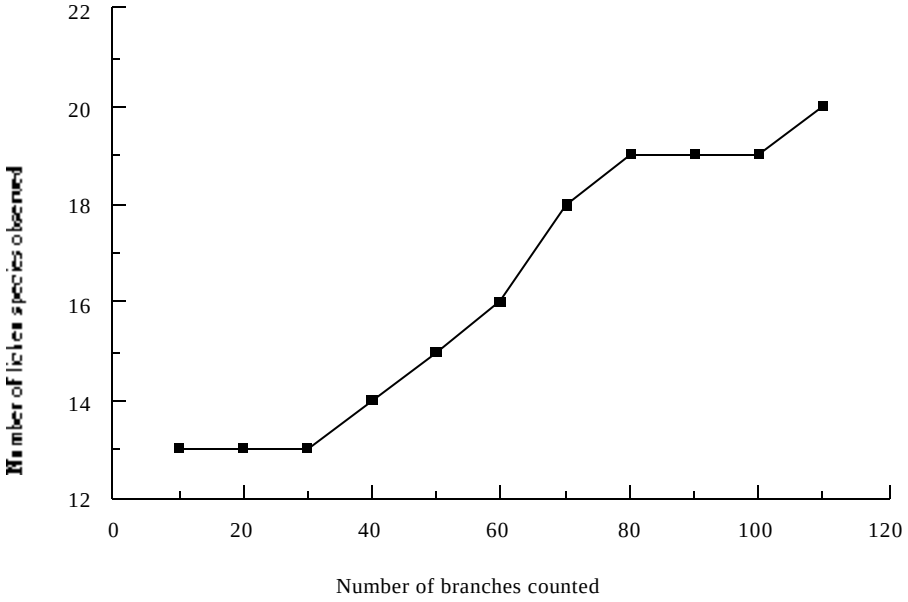
The percentage of plots in which each species occurred was calculated for the following elevation ranges (in feet): 0-5, 10-45, 50-95, 100-190, 200-490, 500-990, 1000-1700, 2000-2990, and 3000-4000. The entire database was used, including collecting areas. A Pearson correlation matrix was calculated from this data. The correlation matrix was used in a multi-dimensional scaling analysis and in a cluster analysis to produce a single linkage tree diagram.

2.5 Quantitative lichen community analysis of old-growth shorepine muskegs and western hemlock forests

Permanent plots for branch community analysis were set up at western hemlock and shorepine sites. These plots were photographed and detailed instructions were written for plot relocation. Intensive branch macrolichen community data was collected:

1) At shorepine plots, 10 trees over 2.7 m tall were selected and white nylon twine was tied at waist height around the trunk. The number of knots tied indicated the tree number (1-10). The dbh and

a)



b)

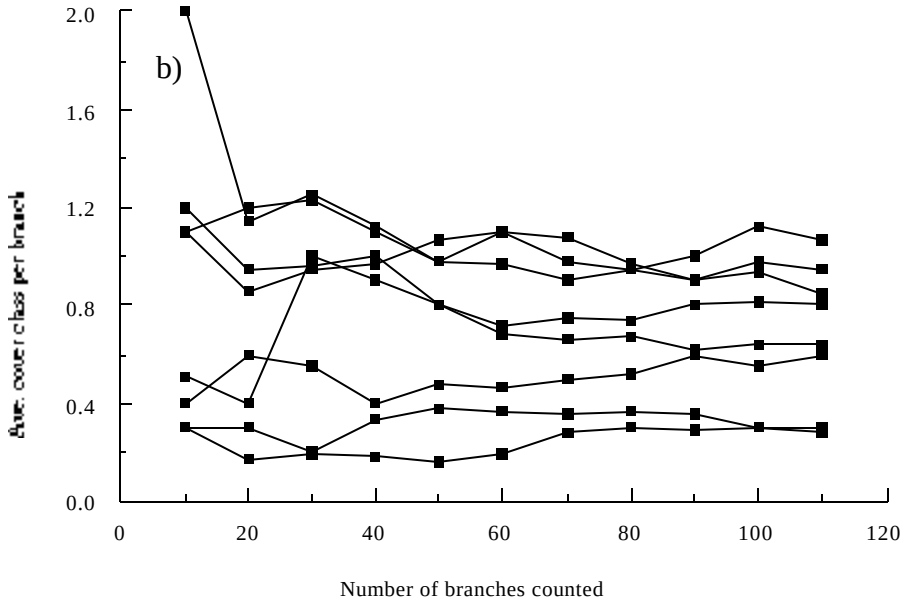


Figure 5. Effect of number of branches counted on estimations of a) species richness and b) abundance of some common lichens.

height of each tree was recorded. The upper surface of the first 30 cm. of branch, beginning at the trunk, was non-destructively examined for lichens using a method developed by McCune (1990). Each species present was recorded along with its percent cover. Abundance classifications were 1 (1-2%), 2 (2-5%), 3 (5-25%), 4 (25-50%), 5 (50-75%), 6 (75-95%), 7 (95-99%) and 8 (99-100%). All measurements were made with a marked ruler. Four branches within reach were measured, preferably one in each direction (N, E, S, W).

2) At western hemlock plots, four evenly spaced transects across the diameter and through the center of the plots were made (visualized as a pie cut into eight pieces). Walking along each transect, the observer stopped each meter to pick up the branch with the most lichens. The selection area for each branch was a rectangle 1m. long and 4 m. wide. The total number of branches collected at each plot was 120. The best 30 cm. of each branch was measured for number and % cover of lichen species (as described above). Branches of all diameters and lengths were collected. Branches adhered to the ground by overgrown moss or consisting only of curled bark were avoided. Counting 60 or more branches yielded a 10-15% error in species abundance estimations for the most common lichens but twice as many branches had to be counted to capture most of the species richness (**Fig. 5**). Sampling all areas of the plot equally was necessary because branch and lichen abundance could vary substantially within a plot according to tree locations and age. Branches which appeared to have the most species and cover, rather than the first branch, were collected. Since most branches did not have macrolichens, this reduced the number of branches needed to achieve a 10-15% precision for cover class of common lichens and species richness.

(The analysis will be published under separate title.)

2.5 Preliminary study near an air pollution point source

In 1990, a preliminary study around the Sitka vicinity was made to test the sensitivity of the monitoring methods and to delimit local air pollution impacts on the National Forest, particularly from the Alaska Pulp Corp. (APC) pulp mill at Sawmill Cove in Silver Bay, approximately four miles southeast of Sitka. The National Forest boundary is within 0.3 miles of this mill.

Study design:

1) Lichens were collected for tissue analysis from 16 locations in a non-linear transect beginning two miles east of APC on Blue Lake Road, following the road toward the mill then wrapped northwest around the mill along Heart/Thimbleberry Lake trail, joining the main road at the trail head 2.5. road miles from APC and continuing north on paved roads past the town incinerator through the city and past the ferry terminal, where the pavement ends, to the road terminus 13 miles from APC. Collection points are marked in **Fig. 33**. This transect was chosen to follow the primary wind directions recorded during an eight month period from

February to September 1991 (ENSR, 1992). Wind roses indicated the primary wind directions are essentially bimodal: N, SSE, S, NNE, and SE.

2) A photographic survey of lichen species diversity and abundance on red alder was made along the same transect except the trail section was omitted and the transect followed the main road from the Blue Lake Rd. intersection. Lichens were photographed on mature alder trunks every 0.5 miles up to 3 miles in each direction from the mill and every mile thereafter northward. The first alder of at least 5" dbh nearest to the mile marker was chosen.

3) A casual survey and lichen collection was made inside the National Forest for several miles north and east of the APC mill as far as Blue Lake, along the Indian River trail (2.6 km) and the Hart /Thimbleberry Lake trail (<2 km from the mill) to estimate the area of impact and note lichen species present.

Data analysis

Due to the preliminary nature of this investigation and the paucity of lichens, only a single repetition was collected from each site and it was not possible to use one species for all collections. To compare tissue analysis data from point to point, the data were separated by species and standardized.

3. RESULTS AND DISCUSSION

3.1 Plots: data summary and conclusions

A summary of the plot data is given in **Appendix A**, including plot locations, elevation, landform, percent canopy, stand height, plant association and number of lichen species observed.

A good distribution of permanent plots among the administrative districts of the Tongass National Forest was achieved (**Fig. 6**). Temporary plots and collecting areas emphasized the Stikine Area.

Figure 6. Distribution of plots among administrative districts of the Tongass National Forest.

Area	Permanent Plots	Temporary Plots	Collecting Areas
Chatham	29	22	9
Ketchikan	21	16	6
Stikine	23	62	31
Total	73	100	47

There was a strong bias toward low elevation plots. Approximately 87% of all plots and collection areas were between sea level and 500 feet (**Fig. 7**).

Figure 7. Distribution of plots by elevation.

Elevation (ft.)	# of Plots	% of Plots
0	76	36.71
50	35	16.91
100	28	13.53
200	22	10.63
500	20	9.66
1000	10	4.83
1500	2	0.97
2000	1	0.48
2500	3	1.45
3000	4	1.93
3500	4	1.93
4000	2	0.97
>4000	0	0

Forested plant associations were well represented (**Fig. 8**). There was an emphasis on western hemlock old-growth, the most abundant plant series on the Tongass National Forest, and shorepine muskegs. **Fig. 8** does not include collecting areas.

Figure 8. Distribution of plots within forested plant communities. PP= permanent plots, TP = temporary plots.

Plant Series	Total	Plant Association	PP	TP	Total
Mixed Conifer	12	*Mixed Conifer/Vaccinium*		3	3
		Mixed Conifer/Vaccinium/Fauria cristae-galli		3	3
		Mixed Conifer/Vaccinium/ Lysichitum americanum		6	6
Shorepine	57	*Pinus contorta/Carex sitchensis*	2		2
		Pinus contorta/Empetrum nigrum	47	6	53
		Pinus contorta/Vaccinium	2		2
Sitka spruce	20	*Picea sitchensis/Calamagrostis nutkatensis*		1	1
		Picea sitchensis/Oplopanax horridum		3	4
		Picea sitchensis/Oplopanax horridum/Rubus spectabilis		4	4
		Picea sitchensis/Oplopanax horridum/Circea alpina		1	1
		Picea sitchensis/Vaccinium		4	4
		Picea sitchensis/Vaccinium-Oplopanax horridum		6	6
Sitka spruce/ Hardwoods	15	*Picea sitchensis-Populus trichocarpa*		2	2
		Picea sitchensis-Populus trichocarpa/Oplopanax horridum/Circea alpina		2	2
		Picea sitchensis/ Alnus sinuata-Vaccinium		7	7
		Picea sitchensis/Alnus-Oplopanax horridum		3	3
		Picea sitchensis/Salix/Vaccinium		1	1
Black Cottonwood	9	*Populus trichocarpa/Alnus*		2	2
		Populus trichocarpa/Alnus-Oplopanax horridum		3	3
		Populus trichocarpa/Alnus-Rubus specatabilis		2	2
		Populus trichocarpa/Equisetum		1	1
		Populus trichocarpa/Salix		1	1
Willow	5	*Salix*		3	3
		Salix/Alnus		2	2
Western hemlock	40	*Tsuga heterophylla-Chamaecyparis nootkatensis/Vaccinium*	1	2	3
		Tsuga heterophylla-Chamaecyparis nootkatensis/Vaccinium/Lysichitum americanum		2	2
		Tsuga heterophylla-Thuja plicata/Vaccinium		2	2
		Tsuga heterophylla-Thuja plicata/Vaccinium/Lysichitum americanum		1	1
		Tsuga heterophylla/Oplopanax horridum	1	1	2
		Tsuga heterophylla/Vaccinium	4	1	5
		Tsuga heterophylla/Vaccinium-Oplopanax horridum	3	4	7
		Tsuga heterophylla/Vaccinium/Dryopteris austriaca	7	6	13
		Tsuga heterophylla/Vaccinium/Lysichitum americanum	4	2	6
Mountain hemlock	13	*Tsuga mertensiana/Circea alpina*		3	3
		Tsuga mertensiana/Circea alpina/Fauria cristae-galli		5	5
		Tsuga mertensiana/Vaccinium		2	2
		Tsuga mertensiana/Vaccinium/Fauria cristae-galli		1	1
		Tsuga mertensiana/Vaccinium/Lysichitum americanum		2	2
Totals	171		71	100	171

Data was collected from most southeastern Alaska landforms (**Fig. 9**).

Figure 9. Distribution of plots among landforms.

Landform		# plots	% of plots
Beaches	Beaches and dunes	13	
	Rock headlands	1	
	Uplifted beaches	4	
	Small marine islands	4	
		22	10
Valleys	Estuaries	2	
	Floodplains	24	
	Outburst floodplains	5	
		31	14
Lowlands	Flat lowlands	39	
	Gently sloping lowlands	37	
	Infrequently dissected volcanic plains	4	
	Infrequently dissected footslopes	4	
	Frequently dissected footslopes	6	
		90	41
Hills	Rolling hill country	14	
	Infrequently dissected, smooth hillslopes	4	
	Freq. dissected, deeply incised mountain slopes	12	
	Broken hill slopes	5	
		35	16
Mountain slopes	Smooth mountain slopes	9	
	Infrequently dissected, smooth mountain slopes	11	
	Broken mountain slopes	10	
		30	13
Alpine	Rounded mountain summits	13	6
	Total	221	100

3.2 Element Analyses

3.21 Discussion of procedural error and sample variability

Detection limits of ICP-AES

Laboratory detection limits for ICP-AES analyses are presented in **Fig. 10**. Detection limits are for the ash solution. Dry matter detection limits are 10-20 times higher than the solution values shown.

Figure 10. Laboratory detection limits of ICP-AES at the Soil Testing and Research Analytical Laboratory, Dept. of Soil Science, Univ. of Minnesota.

Element	Detection Limit (ppm)	Element	Detection Limit (ppm)
P	0.228	Zn	0.007
K	0.311	Cu	0.007
Ca	0.048	B	0.006
Mg	0.033	Pb	0.089
Al	0.040	Ni	0.029
Fe	0.008	Cr	0.005
Na	0.094	Cd	0.006
Mn	0.002		

Quality control "check" standards for ICP-AES

During ICP-AES analysis in 1989 and 1990, a total of 51 samples of a quality control (QC) standard (an artificial standard solution containing all elements in amounts similar to those found in peat) were run with the lichen samples. The standard is used to check instrument calibration after every ten samples: if a value of any element drifts beyond 5% of the actual concentration, the instrument is recalibrated against all elements in the standard. **Fig. 11** indicates error to be expected from the analytical procedure itself. Coefficients of variation were generally less than 3%. These values are within the range commonly seen for this standard. Variation of lead, nickel and chromium was somewhat higher (about 4-7%). In general, repeated measures of a single sample having a concentration of an element of at least 50 times the detection limit show coefficients of variation of about 1-2% (R. Munter, personal communication).

Figure 11. ICP-AES Quality Control "check". Statistics for 51 replicate analyses run with lichen samples during 1989 and 1990. Values in ppm.

Element	Actual Concentration	Experimental Mean	Standard Deviation	Coefficient of Variation (%)
P	250	248.99	5.66	2.27
K	1000	1004.58	27.31	2.72
Ca	1000	996.52	16.54	1.66
Mg	250	249.98	3.99	1.50
Al	10	10.02	0.19	1.94
Fe	10	10.04	0.20	1.99
Na	100	100.00	1.59	1.59
Mn	10	9.96	0.15	1.49
Zn	10	9.96	0.20	1.97
Cu	10	10.07	0.26	2.59
B	2	2.01	0.06	2.81
Pb	5	5.04	0.21	4.11
Ni	2	1.98	0.14	7.09
Cr	2	2.01	0.08	3.91
Cd	2	1.99	0.04	2.15

Reference Standards for Sulfur and Nitrogen analysis

Historical laboratory mean and means for our samples (experimental mean) are compared in **Fig. 12** (R. Eliason, personal communication) for reference standards used in the sulfur and nitrogen analyses.

Figure 12. Sulfur and nitrogen statistics for cumulative and current runs of reference standards.

Element	Standard	certified value % dry wt.	Lab ave. % dry wt.	s.d.	Tongass ave. % dry wt.	s.d.
S	commercially prepared Peach leaves (Alpha Resources, Stevensville, MI)	0.166	0.1651 (76 runs)	0.0052	0.1613 (6 runs)	0.004
S	NIST 1572 Citrus Leaves	0.407	0.4053 (396 runs)	0.0157	0.3890 (3 runs)	0.018
N	NIST 1575 Pine Needles (non-certified)	1.2	1.183 (182 runs)	0.037	not reported	not reported

Reference lichen standard

Samples of the lichen, *Alectoria sarmentosa,* collected in bulk from a single location on Mitkof Island about 15 miles south of Petersburg were included in both the ICP-AES and sulfur analyses. This data was collected to indicate the expected level of laboratory variation in the analysis of lichens (**Fig. 13**) and for comparison to future runs.

The coefficients of variation were under 3%, similar to the peat standards, for about half the elements. Sulfur, aluminum, and sodium showed greater variability (6.2-7.3%). The variability in sulfur may reflect the different procedure used. Lead, nickel, chromium, and cadmium were highly variable (28.2- 100.5) because these values were measured very close to the detection limits of the instrument. Reducing this variability should be an objective of future analytical work.

Analytical splits

Following lichen sample preparation, a few samples were randomly chosen and split into two subsamples which were run independently during the ICP-AES or S analysis. There were 6 such samples for ICP-AES and 24 for sulfur in 1990. For each pair of observations, the difference (as percent of the mean) was calculated for each element (**Fig. 14**). The average percent difference for analytical splits among these elements was 5.13%, excluding lead, nickel, chromium and cadmium. This variability is approximately the same as that seen among field replications for a given species/site/habitat collection. Like the Mitkof Is. duplicates of *A. sarmentosa*, the variability for lead, nickel, chromium, and cadmium field samples was very high because the measurements were made near the detection limits of the instrument. This is a problem which should be addressed in the future.

Figure 13. Reference lichen (*Alectoria sarmentosa*) statistics. Means of 4 ICP-AES samples and 6 S samples analyzed with field samples.

Element	Experimental Mean (ppm)	Standard Deviation	Coefficient of Variation (%)
S	304.17	2.11	6.93
P	191.70	2.79	1.46
K	1122.57	22.77	2.03
Ca	2807.05	44.57	1.59
Mg	242.81	2.95	1.21
Al	35.40	2.18	6.16
Fe	30.99	0.90	2.90
Na	38.43	2.82	7.32
Mn	82.54	1.78	2.15
Zn	19.89	0.48	2.39
Cu	0.85	0.08	9.21
B	4.65	0.07	1.59
Pb	5.36	2.04	38.02
Ni	0.53	0.15	28.16
Cr	0.46	0.46	100.51
Cd	0.29	0.23	80.20

Figure 14. Differences between 6 ICP-AES and 24 S analytical splits in 1990.

Element	Ave. % Difference between analytical splits	Standard Deviation
S	4.94	4.04
P	2.35	2.30
K	1.49	1.42
Ca	4.97	2.28
Mg	2.24	2.65
Al	6.24	3.95
Fe	4.54	3.46
Na	5.29	4.04
Mn	3.45	3.41
Zn	1.67	1.31
Cu	9.38	12.47
B	9.91	5.45
Pb	39.64	31.98
Ni	20.80	18.65
Cr	67.82	51.66
Cd	32.76	35.38

3.22 Description of the data

1989/90: Seventy-one samples from 1989 and 197 samples from 1990 were analyzed for sulfur and 15 other elements. The two year data pool consists of 268 samples. Of these, 113 are from *Alectoria sarmentosa*, 42 from *Cladina rangiferina*, 49 from *Hypogymnia enteromorpha* , and 74 from *Lobaria oregana*. The laboratory data are presented in **Appendix B**. Levels of all elements were within the detection level of the

instruments with the exception of cadmium, nickel, chromium and lead. For these between 35 and 50% of the samples were below the detection limit and were reported by the laboratory as the lowest detectable level.

1991/92: Ninety-eight samples of *A. sarmentosa,* collected from 33 permanent plots in shorepine forests during 1991 and 1992, were analyzed for nitrogen. These data are presented in **Appendix C**.

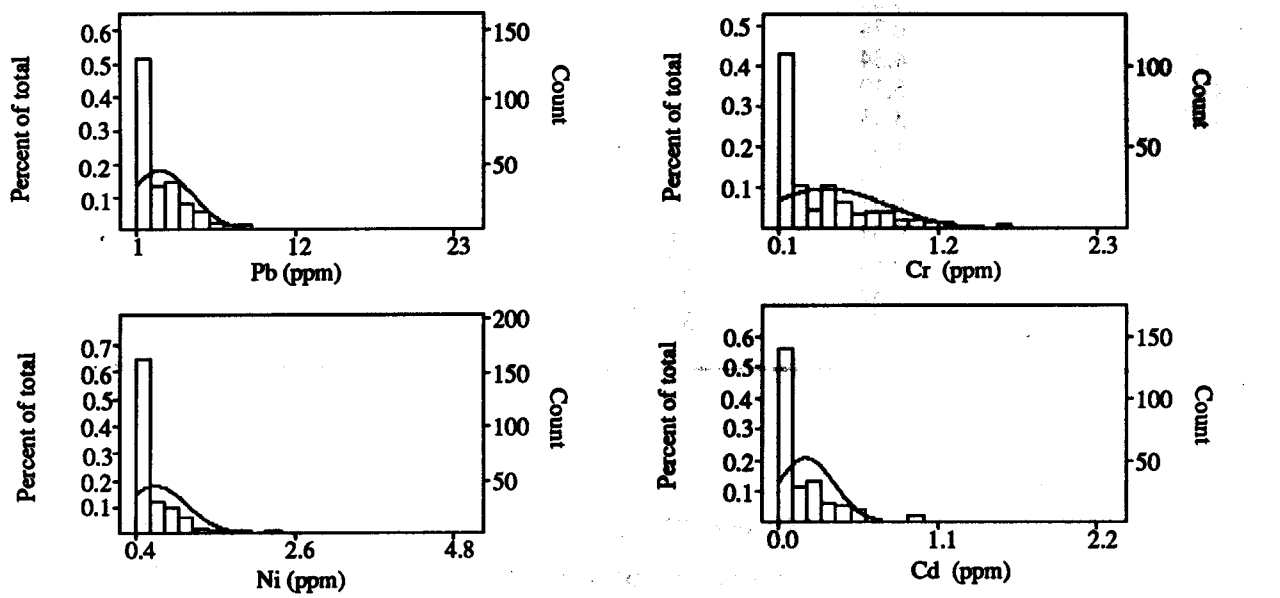
3.23 Normalization of the data

The database was not log transformed because transformation did not improve linearity and most elements had a close to normal distribution when separated by lichen species and year. In order to account for data points below the detection limit and to calculate more realistic means for lead, nickel, chromium and cadmium, all values at or below the detection limit were replaced by values along a normal distribution curve. This was done using the following expressions:

If Pb $\leq$1.09 then Pb normalized = (-1* ABS(ZRN)/12) + 1.08
If Ni $\leq$0.46, then Ni normalized = (-1*ABS(ZRN)/ 16) + 0.45
If Cr $\leq$ 0.12, then Cr normalized = (-1*ABS(ZRN)/25) + 0.11
If Cd $\leq$ 0.10, then Cd normalized = (-1*ABS(ZRN)/40) + 0.09,

where 'ABS' means 'absolute value' and 'ZRN' is a random variate function which generates pseudo-random values from a normal distribution with mean zero and standard deviation one. **Fig. 15** presents density histograms for these four elements with superimposed normal distributions.

Figure 15. Normal distribution superimposed on Pb, Ni, Cr, and Cd density histograms.



3.24 Influence of lichen species on tissue element concentrations

Analysis of variance indicated that the most important variable was species. Baseline values differed significantly between at least two species for every element. *H. enteromorpha* accumulated significantly more magnesium, aluminum, iron, manganese, boron, nickel, chromium and cadmium than any of the other species.

3.25 Temporal variability

Some temporal variability was observed in an analysis of variance of the 1989, 1990 and 1992 data between species/element combinations. There was a statistically significant decrease in sulfur in *A. sarmentosa* between 1989 and 1992. There were increases in cadmium, nickel, manganes, calcium, and a decrease in phosphorus from 1989 to 1990 across three species (*C. rangiferina* was only analyzed in 1990). Due to significant year to year variability the data was not combined and the baselines were established as the average of 1989-1992 means.

3.26 Spatial variability

To examine effects of plot location, data were separated by species and year. Analysis of variance was used to compare standardized data, element by element, according to general location collected. Although individual element/species/location combinations varied significantly, there were no trends due to longitude or latitude, e.g. Yakutat in the northern extreme of the Chatham Area was not predictably higher or lower than Dog Island in the southern Ketchikan Area. Analysis of variance and the Tukey probability test indicated that nitrogen content of *A. sarmentosa* between many of the locations was particularly variable. A multivariate analysis might reveal subtle patterns in groups of elements by geographical distribution.

3.27 Effect of substrate and habitat

Analysis of variance indicated some significant differences in sodium and calcium accumulation in each of the four species according to vegetation type. Sodium accumulation was significantly higher at beach sites. Calcium accumulation was low at the alpine site. No differences in sulfur accumulation were seen according to habitat in non-impacted areas. Lastly, there were no statistically significant differences between tissue analysis samples collected in open shorepine forests vs. closed western hemlock forest plots (except for manganese/*A. sarmentosa* and copper/*H. enteromorpha* where values were higher at western hemlock plots). Therefore, except for manganese and copper, samples collected from either association should be comparable. The number of repetitions of each species by habitat is displayed in **Fig. 16**.

Figure 16. Distribution of element analysis data by plant series/habitat and lichen species.

Vegetation Type	*A. sarmentosa*	*C. rangiferina*	*H. enteromorpha*	*L. oregana*	Total
Sitka Spruce	5	0	4	10	19
Black Cottonwood	2	0	0	4	6
Western Hemlock	36	0	18	36	40
Mixed Conifer	12	0	0	3	15
Red Cedar	2	0	2	3	7
Mountain Hemlock	5	0	1	3	9
Shorepine muskegs	38	42	12	0	92
Beach Sites	3	0	4	7	14
Roadside alder	5	0	11	1	17
Alpine	3	0	0	0	3
Total	111	42	52	67	221

3.28 Establishment of baselines for lichen element concentrations

The following plots were eliminated from the baseline:

- All collections within 15 miles of the city of Sitka.
- Plot 1-7.5.90 in Yakutat, which was next to a gravel road and mining site.
- Plot 1-7.19.90 on the beach edge at Kell Bay. Elevated Ca, Mg, and Na values indicate the lichens were probably influenced by salt spray.

Statistics for Forest-wide baselines by element, lichen species and year are presented in **Fig. 17**. Most elements are slightly skewed to the right compared to a normal distribution curve. This is reasonable since lichens have biologically or atmospherically limited minimums. In contrast, maximums can vary considerably depending on levels of atmospheric dust, salt and pollutants. Skewness was generally less than one or two for most species/year/element combinations and larger than two for most combinations only for sodium, boron, and nickel. Kurtosis was generally positive, indicating the data fit more tightly around the mean than a normal distribution curve-- which would improve the sensitivity of the method compared to normally distributed data. Variance was homogeneous for some combinations but not others. The variance for sulfur was zero for all combinations.

Baseline values were established and are presented in **Fig. 18**. Note values are averages of 1989,1990 and (for sulfur content of *A. sarmentosa*) 1992 . Exceptions to this are values for *C. rangiferina*, which was only analyzed in 1990, and nitrogen values for *A. sarmentosa*, which were only analyzed in 1992. Baseline values should be valid for any general location in the Tongass National Forest.

3.29 Evaluation of baselines: biological significance and comparison to literature values

Baseline values from the Tongass National Forest are compared to other U.S. national parks and forests in **Fig. 19**.

Figure 17. Statistics of baseline element analysis data by lichen species, year and element.
(Sulfur reported as % dry weight, other data as ppm).

Lichen = *Alectoria sarmentosa*
Year = 1989
Number of observations: 35

	S	P	K	CA	MG	AL	FE	NA
MINIMUM	0.021	167.200	220.800	251.520	111.810	5.950	5.030	12.330
MAXIMUM	0.067	1028.300	2386.900	11341.000	854.270	39.610	21.940	473.160
MEAN	0.037	471.589	1366.627	3359.097	315.799	24.577	10.413	80.723
VARIANCE	0.000	59616.452	149551.728	8471114.487	45763.925	97.770	19.466	9769.002
STD. ERROR	0.002	41.271	65.367	491.967	36.160	1.671	0.746	16.707
SKEWNESS(G1)	1.129	0.770	0.237	1.144	1.266	-0.389	0.900	2.554
KURTOSIS(G2)	1.964	-0.201	2.147	0.428	0.420	-0.922	-0.330	6.466
C.V.	0.238	0.518	0.283	0.866	0.677	0.402	0.424	1.224

	MN	ZN	CU	B	PB	NI	CR	CD
MINIMUM	51.170	11.990	0.230	0.230	1.040	0.450	0.110	0.080
MAXIMUM	301.780	49.060	1.340	5.470	5.930	2.130	0.560	0.380
MEAN	109.715	23.585	0.711	0.961	2.785	0.735	0.263	0.120
VARIANCE	3017.464	56.780	0.071	1.039	2.111	0.128	0.020	0.005
STD. ERROR	9.285	1.274	0.045	0.172	0.246	0.060	0.024	0.011
SKEWNESS(G1)	2.063	1.127	0.373	2.976	0.477	2.084	0.489	2.158
KURTOSIS(G2)	4.353	2.076	0.079	9.618	-0.733	4.994	-1.020	4.646
C.V.	0.501	0.319	0.374	1.061	0.522	0.486	0.538	0.559

Lichen = *Alectoria sarmentosa*
Year = 1990
Number of observations: 74

	S	P	K	CA	MG	AL	FE	NA
MINIMUM	0.014	93.480	657.730	238.330	118.390	12.960	3.540	16.580
MAXIMUM	0.061	1068.000	2500.800	11825.000	681.900	64.450	250.440	1532.000
MEAN	0.030	247.697	1107.597	3977.151	309.945	32.519	23.621	145.357
VARIANCE	0.000	27321.403	125539.859	8584256.323	17926.287	112.577	914.961	40933.097
STD. ERROR	0.001	19.215	41.188	340.593	15.564	1.233	3.516	23.519
SKEWNESS(G1)	1.277	2.391	1.557	1.012	1.059	0.143	5.919	4.693
KURTOSIS(G2)	2.758	7.175	2.641	0.036	0.479	-0.217	41.175	28.212
C.V.	0.255	0.667	0.320	0.737	0.432	0.326	1.281	1.392

	MN	ZN	CU	B	PB	NI	CR	CD
MINIMUM	2.470	5.400	0.050	0.060	1.080	0.450	0.110	0.080
MAXIMUM	286.630	38.900	1.990	7.150	8.870	1.210	1.700	0.960
MEAN	66.077	20.592	0.836	1.339	2.832	0.531	0.419	0.215
VARIANCE	4140.774	44.978	0.126	2.158	3.648	0.027	0.141	0.032
STD. ERROR	7.480	0.780	0.041	0.171	0.222	0.019	0.044	0.021
SKEWNESS(G1)	1.477	0.362	0.096	2.693	0.913	2.400	1.337	1.576
KURTOSIS(G2)	1.882	-0.341	1.153	7.157	0.185	5.335	1.195	2.858
C.V.	0.974	0.326	0.424	1.097	0.674	0.311	0.897	0.836

Lichen = *Cladina rangiferina*
Year = 1990
Number of observations: 39

	S	P	K	CA	MG	AL	FE	NA
MINIMUM	0.018	145.700	489.440	355.860	261.040	23.620	21.000	14.120
MAXIMUM	0.038	365.740	1389.800	1068.500	724.500	62.200	93.460	235.140
MEAN	0.027	230.803	926.172	574.582	436.866	40.116	50.097	59.278
VARIANCE	0.000	3382.768	34610.567	26268.701	14583.907	132.836	542.680	1976.189
STD. ERROR	0.001	9.313	29.790	25.953	19.338	1.846	3.730	7.118
SKEWNESS(G1)	0.431	0.608	-0.110	1.050	0.575	0.530	0.595	2.243
KURTOSIS(G2)	-0.418	-0.428	0.915	1.356	-0.175	-1.155	-1.132	6.015
C.V.	0.171	0.252	0.201	0.282	0.276	0.287	0.465	0.750

	MN	ZN	CU	B	PB	NI	CR	CD
MINIMUM	15.690	6.260	0.050	0.060	1.080	0.450	0.110	0.080
MAXIMUM	255.990	23.360	1.920	2.740	5.650	1.080	1.870	0.530
MEAN	46.780	11.506	0.742	0.688	1.819	0.519	0.405	0.219
VARIANCE	1842.746	13.469	0.160	0.260	0.985	0.020	0.188	0.021
STD. ERROR	6.874	0.588	0.064	0.082	0.159	0.023	0.069	0.023
SKEWNESS(G1)	3.416	1.164	0.221	2.085	1.745	2.276	1.552	0.679

KURTOSIS(G2)	13.114	1.818	0.764	5.808	3.761	4.986	1.963	-0.706
C.V.	0.918	0.319	0.539	0.741	0.546	0.272	1.070	0.668

Lichen = *Hypogymnia enteromorpha*
Year = 1989
Number of observations: 12

	S	P	K	CA	MG	AL	FE	NA
MINIMUM	0.052	360.850	1283.500	1479.400	163.750	24.780	9.990	12.330
MAXIMUM	0.068	1606.100	3517.500	18592.000	1560.400	844.520	1517.600	473.160
MEAN	0.061	1075.646	2417.233	8618.367	999.624	304.846	348.631	154.153
VARIANCE	0.000	112670.523	372339.661	.264676E+08	160277.732	73328.498	187244.281	14712.727
STD. ERROR	0.001	96.898	176.149	1485.137	115.570	78.171	124.915	35.015
SKEWNESS(G1)	-0.185	-0.316	0.004	0.552	-0.479	0.902	1.827	1.432
KURTOSIS(G2)	-0.795	0.110	-0.463	-0.664	-0.422	-0.570	2.489	2.092
C.V.	0.079	0.312	0.252	0.597	0.400	0.888	1.241	0.787

Figure 17. (cont.)

	MN	ZN	CU	B	PB	NI	CR	CD
MINIMUM	81.050	23.260	2.290	2.320	1.150	0.500	0.140	0.080
MAXIMUM	456.490	51.510	7.340	9.300	9.700	4.210	1.460	0.460
MEAN	230.620	32.042	3.847	4.243	4.117	1.444	0.788	0.163
VARIANCE	17576.111	67.227	1.646	3.164	7.186	1.067	0.112	0.011
STD. ERROR	38.271	2.367	0.370	0.514	0.774	0.298	0.097	0.031
SKEWNESS(G1)	0.699	1.058	1.702	1.987	0.827	1.684	0.178	1.885
KURTOSIS(G2)	-0.832	0.538	2.741	3.673	-0.208	2.370	0.332	2.966
C.V.	0.575	0.256	0.333	0.419	0.651	0.715	0.425	0.656

Lichen = *Hypogymnia enteromorpha*
Year = 1990
Number of observations: 26

	S	P	K	CA	MG	AL	FE	NA
MINIMUM	0.041	283.800	1291.000	3317.100	656.300	132.750	49.840	41.470
MAXIMUM	0.066	1647.000	3775.000	23261.000	7891.560	494.700	956.550	845.420
MEAN	0.055	713.381	2061.888	11966.946	1313.855	211.363	233.739	151.757
VARIANCE	0.000	173557.983	474429.301	.289890E+08	1898266.250	4871.622	32296.772	35132.675
STD. ERROR	0.001	81.703	135.082	1055.917	270.204	13.688	35.245	36.759
SKEWNESS(G1)	-0.267	1.086	0.871	0.311	4.417	2.692	2.663	2.643
KURTOSIS(G2)	-1.088	0.023	-0.209	-0.640	18.623	8.604	8.206	6.272
C.V.	0.135	0.584	0.334	0.450	1.049	0.330	0.769	1.235

	MN	ZN	CU	B	PB	NI	CR	CD
MINIMUM	15.290	19.120	2.000	1.270	1.080	0.450	0.110	0.080
MAXIMUM	707.340	54.660	278.170	10.630	15.980	3.660	2.130	0.980
MEAN	271.255	34.606	20.400	2.835	5.353	1.041	0.708	0.327
VARIANCE	26506.425	61.662	3544.382	3.976	12.899	0.538	0.361	0.093
STD. ERROR	31.929	1.540	11.676	0.391	0.704	0.144	0.118	0.060
SKEWNESS(G1)	0.556	0.036	3.657	2.529	0.982	2.058	1.032	1.046
KURTOSIS(G2)	0.227	0.586	12.407	7.018	1.127	4.491	0.126	-0.332
C.V.	0.600	0.227	2.918	0.703	0.671	0.705	0.848	0.934

Lichen = *Lobaria oregana*
Year = 1989
Number of observations: 24

	S	P	K	CA	MG	AL	FE	NA
MINIMUM	0.087	880.330	2085.100	237.450	329.680	15.450	17.860	17.580
MAXIMUM	0.136	3805.500	8219.000	5327.600	788.650	106.870	198.600	300.670
MEAN	0.106	1911.947	6269.007	577.012	499.091	48.602	58.836	101.518
VARIANCE	0.000	453959.427	1613277.721	1029531.021	15554.583	821.437	2043.222	7940.104
STD. ERROR	0.003	137.532	259.268	207.116	25.458	5.850	9.227	18.189
SKEWNESS(G1)	0.596	0.860	-1.567	4.546	0.618	0.668	2.171	1.177
KURTOSIS(G2)	-1.167	0.801	3.114	18.804	-0.476	-0.914	4.106	0.077
C.V.	0.161	0.352	0.203	1.758	0.250	0.590	0.768	0.878

	MN	ZN	CU	B	PB	NI	CR	CD
MINIMUM	30.640	14.320	0.820	0.800	1.100	0.450	0.110	0.080
MAXIMUM	218.730	65.400	6.590	2.540	3.320	1.340	1.200	0.520
MEAN	75.299	36.005	3.243	1.566	1.987	0.612	0.342	0.105
VARIANCE	2483.174	229.769	2.494	0.228	0.594	0.043	0.073	0.008
STD. ERROR	10.172	3.094	0.322	0.097	0.157	0.042	0.055	0.018
SKEWNESS(G1)	1.966	0.471	0.117	0.664	0.315	2.068	1.402	4.542
KURTOSIS(G2)	3.247	-0.875	-0.859	-0.695	-1.296	4.271	2.108	18.781
C.V.	0.662	0.421	0.487	0.305	0.388	0.340	0.791	0.844

Lichen = *Lobaria oregana*
Year = 1990
Number of observations: 41

	S	P	K	CA	MG	AL	FE	NA
MINIMUM	0.090	885.000	5115.500	253.920	325.460	13.340	16.940	21.170
MAXIMUM	0.199	2926.400	8499.000	651.500	725.700	130.300	308.200	225.500
MEAN	0.112	1763.380	6943.476	423.932	476.101	38.916	70.530	74.913

VARIANCE	0.000	201350.431	784931.727	7226.145	8753.496	853.656	5667.350	3252.434
STD. ERROR	0.003	70.078	138.364	13.276	14.612	4.563	11.757	8.907
SKEWNESS(G1)	2.080	0.035	-0.526	0.239	1.119	1.902	1.995	1.333
KURTOSIS(G2)	6.817	0.014	-0.792	0.099	1.116	3.047	3.303	0.483
C.V.	0.177	0.254	0.128	0.201	0.197	0.751	1.067	0.761

	MN	ZN	CU	B	PB	NI	CR	CD
MINIMUM	10.730	18.580	0.720	0.330	1.080	0.450	0.110	0.080
MAXIMUM	140.630	92.500	10.880	5.360	4.740	1.050	1.790	1.270
MEAN	54.233	41.706	4.553	1.538	1.442	0.610	0.403	0.174
VARIANCE	994.749	200.632	6.866	1.463	0.535	0.037	0.168	0.060
STD. ERROR	4.926	2.212	0.409	0.189	0.114	0.030	0.064	0.038
SKEWNESS(G1)	0.921	1.138	0.968	1.772	2.837	0.851	1.478	3.124
KURTOSIS(G2)	0.394	2.885	-0.137	2.795	9.055	-0.680	1.681	9.761
C.V.	0.582	0.340	0.575	0.787	0.507	0.316	1.016	1.407

Figure 18. Tongass National Forest baseline tissue concentrations (ppm) and standard error (s.e.) of 17 elements in *Alectoria sarmentosa* (ALSA), *Cladina rangiferina* (CLRA), *Hypogymnia enteromorpha* (HYEN), and *Lobaria oregana* (LOOR).

	ALSA (ppm)		CLRA (ppm)		HYEN (ppm)		LOOR (ppm)	
Element	baseline	std. error	baseline	std. error	baseline	std. error	baseline	std. error
S	320	10	270	10	590	10	1090	20
P	317	20.5	231	8.6	878	66.8	1800	64.1
K	1188	35.7	931	28.1	2213	98.4	6634	130.2
Ca	3860	282	583	25	12168	1101	479	72
Al	30.4	1.1	40.4	1.8	275.8	31.6	44.2	3.7
Fe	20.0	2.4	50.3	3.5	266.5	42.7	71.6	8.6
Na	125.5	16.6	56.8	6.7	258.8	58.1	102.6	15.1
Mn	78.7	6.1	50.9	6.8	231.0	23.9	60.0	4.8
Zn	21.4	0.7	11.5	0.5	34.2	1.5	40.4	1.8
Cu	0.81	0.032	0.76	0.06	3.52	0.19	4.26	0.321
B	1.21	0.13	0.67	0.08	3.67	0.32	1.61	0.123
Pb	2.81	0.17	1.80	0.16	4.96	0.54	1.62	0.10
Ni	0.60	0.02	0.52	0.02	1.17	0.14	0.61	0.02
Cr	0.36	0.03	0.39	0.07	0.73	0.09	0.37	0.05
Cd	0.18	0.01	0.21	0.02	0.27	0.04	0.14	0.03
N	2370	40	--	--	--	--	--	--

Sulfur, Phosphorus, Potassium and Boron (S,P,K and B)

All Tongass National Forest baselines were within background range and comparable to other national parks and forests. *L. oregana* accumulated the highest concentrations of S and K and these levels were higher than the combined genera background levels established by Nieboer and Richardson (1981). This is apparently normal for *L. oregana* in southeastern Alaska because *H. enteromorpha* and *A. sarmentosa* collected from the same locations were within Nieboer and Richardson's background range and were comparable to several Class I national park lands.

Rhoades (1988) noted higher S values in canopy than in the litter but no significant difference was noted for this element on the Tongass National Forest between shorepine plots where the lichens were collected directly off the trees on exposed branches and western hemlock plots, where all the lichens were collected from the litter.

Sources of atmospheric S are both biogenic and anthropogenic. The concentration of total S in plant material has been used extensively to define the impact of point-sources of atmospheric emissions, particularly fossil fuel power-plants. Sulfur can also be an indicator of acid deposition, which is toxic to vegetation (Crock et al., 1992). Phosphorus and potassium are essential macro-nutrients for all organisms. K has been reported to be enriched in some lichens near the seashore (Gough et al., 1987).

Calcium, Magnesium, Sodium, Manganese, Zinc and Cadmium (Ca, Mg, Na, Mn, Zn and Cd)

Tongass National Forest values were generally higher than other national parks and forests. Ca values for *A. sarmentosa* and Ca and Mg for *H. enteromorpha* are high, but all other values were within the combined genera background range established by Nieboer & Richardson (1981). All six of these elements tend to be elevated in areas under marine influence (Davidson et al., 1985; Nieboer et al., 1978; Rhoades, 1988) and this may explain elevated values in the Tongass National Forest. Ca may exceed 40,000 ppm and Mn may reach 350 ppm (or urban/industrial levels) in seashore environments (Nieboer et al., 1978). While Cd can be enhanced near urban/industrial areas, surface layers of the ocean are also sources for this element (Davidson et al., 1985).

Calcium and magnesium are essential macronutrients for all organisms. Calcium plays an important role in moderating plant stress. Most zinc and manganese in the atmosphere is the result of emissions from base metal and voltaic-cell industries. Because both are essential micronutrients to all organisms, instances of toxicity occur only under rare occasions (e.g. gross over-fertilization) (Crock et al., 1992).
Cadmium is a component of anthropogenic atmospheric emissions, mainly from fossil fuel combustion and waste incineration. Cd phytotoxicity is moderate, however, in mammals it tends to accumulate in the liver and kidneys and its toxicity can be very high over time (Crock et al., 1992). Cd concentrations in lichen tissue were low, most being at or near the detection limit.

Aluminum and Iron (Al and Fe)

Tongass National Forest values were generally lower than other national parks and forests, with values for all species well within combined genera background ranges. Al and Fe show enhancement in lichens exposed to mineral soil dust (Rhoades, 1988). The combination of high rainfall, thick organic layer above the mineral horizons, and relatively few roads, all keep dust levels low over much of the Forest. In addition Rhoades (1988) and Wetmore (1985, 1987) used special laboratory procedures to enhance Fe and Al recovery in their studies.

Copper, Lead, Nickel and Chromium (Cu, Pb, Ni and Cr)

Although Cu, Pb, and Ni can be enhanced by marine conditions (Davidson et al., 1985; Rhoades, 1988), Tongass National Forest values were well within combined genera background ranges and were generally lower than other national parks and forests.

Cu is usually of concern only near specialized industrial sources. Although it is an essential nutrient, elevated Cu levels are highly toxic to microorganisms (bacteria, algae, and fungi) and moderately toxic to mammals. The major source of Ni in the atmosphere is fossil fuel combustion and the ferrous metal industry. Ni is considered very toxic to plants but only minimally toxic to animals and humans. Pb originates from numerous diverse industrial sources but has been most frequently associated with contamination near roadways where use of leaded fuels has been a problem. Pb is a common airborne metal and is known to be transported great distances in the atmosphere. Lead can be extremely

Figure 19. Comparison of baseline elemental concentrations (ppm) and standard error (s.e.) of four lichen species on the Tongass National Forest to other United States National Park and Forest values and to international ranges for combined lichen genera.

Element	*Alectoria sarmentosa*				*Cladina rangiferina*						*Hypogymnia enteromorpha*						*Lobaria oregana*		Combined Genera Literature Survey
	Tongass National Forest, SE Alaska		Olympic National Park, Washington (Rhoades, 1988)		Tongass National Forest, SE Alaska		Boundary Waters Canoe Area, Minnesota (Wetmore1987b)		Isle Royale Natl. Park, Michigan (Wetmore, 1985)		Tongass National Forest, SE Alaska		Olympic National Park, Washington (Rhoades, 1988)		Redwood Natl. Park, California (Gough, et.al., 1987)		Tongass National Forest, SE Alaska		Background (Nieboer, et al. 1981)
	ppm	s.e.	ppm	s.e.	ppm	s.e.	ppm	s.e.	ppm	s.e.	ppm	s.e.	ppm	s.e.	ppm		ppm	s.e.	ppm
S	320	10	497	15	270	10	472	13	340	19	590	1	728	28	470		1090	20	<1000
P	317	20	758	46	231	9	500	52	420	18	878	67	1347	33	670		1800	64	
K	118	36	1462	30	931	28	1841	117	1332	35	2213	98	2635	40	1800		6634	130	<5000
Ca	3860	282	2317	379	583	25	571	33	680	73	12168	1101	6400	535	3800		479	13	<1000
Mg	314	15	235	12	429	19	287	15	269	18	1115	62	762	29	1300		493	72	<1000
Al	30.4	1.1	45.1	4.0	40.4	1.8	240	10.4	314	9	275.8	31.6	804.1	64.2	1100		44.2	3.7	<400
Fe	20.0	2.4	18.8	1.0	50.3	3.5	205	13.6	297	12	266.5	42.7	958.7	102.4	850		71.6	8.6	<1400
Na	125.5	16.6	66.5	4.0	56.8	6.7	28.9	1.8	29.9	1.3	258.8	58.1	136.9	6.9	320		102.6	15.1	<1000
Mn	78.7	6.1	74.7	16.2	50.9	6.8	45.3	6.4	26.1	2.3	231.0	23.9	226.0	33.7	89		60.0	4.8	< 130
Zn	21.4	0.6	19.6	0.8	11.5	0.5	15.6	0.8	14.7	0.4	34.2	1.4	35.0	0.8	25		40.4	1.8	< 500
Cu	0.81	0.03	1.16	0.07	0.76	0.06	1.6	.08	1.89	0.05	3.52	0.19	5.79	0.22	3.7		4.26	0.32	< 50
B	1.21	0.13	1.45	0.13	0.67	0.08	1.7	.08	1.22	0.15	3.67	0.32	3.18	0.20			1.61	0.12	
Pb	2.79	0.17	4.69	0.63	1.90	0.15	1.4	0.14	7.90	0.21	4.80	0.48	26.70	2.25	12		1.62	0.09	< 5
Ni	0.59	0.02	0.63	0.06	0.52	0.02	0.59	0.04	0.75	0.05	1.12	0.13	3.01	0.21	11		0.61	0.02	< 5
Cr	0.38	0.03	0.45	0.03	0.38	0.06	0.4	0.01	0.43	0.02	0.73	0.08	1.78	0.17	4.9		0.38	0.04	< 10
Cd	0.18	0.01	0.04	0.00	0.23	0.02	0.16	0.01	0.27	0.05	0.26	0.04	0.09				0.14	0.02	< 30

phytotoxic. Its toxicity to mammals is considered moderate but cumulative. Although industrial iron and steel mills are the major contributor of anthropogenic Cr in the atmosphere, fossil fuel combustion does contribute to the overall atmospheric Cr burden. Cr toxicity depends on its oxidation state, Cr (VI) being much more toxic than the environmentally most common Cr (III) form (Crock et al., 1992).

3.3 Lichen Inventory

3.31 Forest-wide lichen inventory

The inventory documented 101 genera, 381 species, and 20 subspecies, varieties and forms of lichens from the Tongass National Forest (**Fig. 19**). Scientific nomenclature follows Egan (1987) and subsequent updates (Egan, 1989, 1990 and 1991). Vouchers are in the Forest Service herbarium in Petersburg, Alaska. Duplicates were sent to herbaria at the Smithsonian Institution, the Canadian National Museum, Oregon State University, the University of Alaska at Fairbanks, and the University of Washington, Seattle.

The lichen flora of southeastern Alaska is rich and varied. Many poorly known and rare species, threatened by habitat disturbance and air pollution elsewhere, occur on the Tongass National Forest. For example *Lobaria scrobiculata* was formerly recorded from more than 300 localities in Sweden. Due to acid rain, it has now disappeared completely from the south of the country and is rare everywhere else (Hallinback, 1989). *Usnea longissima*, once common throughout central Scandinavia and the European Alps is now on threatened and endangered lists throughout its former habitat range, a result of combined effects of air pollution and short timber harvest cycles (Moberg and Homåsen, 1992). Both these species are common in southeastern Alaska. A more detailed account of the inventory, including species habitat requirements, range and abundance information, distribution maps, notes on range extensions and on sensitive, endemic and rare species, and collections previous to this study, has been published under separate title (Geiser et al., 1994).

Alectoria nigricans (Ach.) Nyl.
Alectoria ochroleuca (Hoffm.) Mass.
Alectoria sarmentosa (Ach.) Ach.
subsp. sarmentosa

Allantoparmelia almquistii (Vainio) Essl.
Allantoparmelia sibirica Zahlbr.

Amygdalaria consentiens (Nyl.) Hertel, Brodo & M. Inoue
Amygdalaria elegantior (Magnusson) Hertel & Brodo
Amygdalaria haidensis Brodo & Hertel
Amygdalaria panaeola (Ach.) Hertel & Brodo
Amygdalaria subdissentiens (Nyl.) M. Inoue & Brodo

Arctomia delicatula Th. Fr.

Arctoparmelia centrifuga (L.) Hale
Arctoparmelia separata (Th. Fr.) Hale

Bacidia nivalis Follm.
Bacidia phacodes Körber

Baeomyces placophyllus Ach.
Baeomyces rufus (Huds.) Rebent.

Bellemerea cinereorufescens (Ach.) Clauz. & Roux

Brigantiaea fuscolutea (Dickson) R. Sant. *in* Poelt & Vezda

Brodoa oroarctica (Krog) Goward

Bryocaulon divergens (Ach.) Kärnef.
Bryocaulon pseudosatoanum (Asahina) Kärnef.

Bryoria bicolor (Ehrh.) Brodo & D. Hawksw.
Bryoria capillaris (Ach.) Brodo & D. Hawksw.
Bryoria carlottae Brodo & D. Hawksw.
Bryoria cervinula Mot. ex Brodo & D. Hawksw.
Bryoria chalybeiformis (L.) Brodo & D. Hawksw.
Bryoria fremontii (Tuck.) Brodo & D. Hawksw.
Bryoria friabilis Brodo & D. Hawksw.
Bryoria fuscescens (Gyeln.) Brodo & D. Hawksw.
Bryoria glabra (Mot.) Brodo & D. Hawksw.
Bryoria lanestris (Ach.) Brodo & D. Hawskw.
Bryoria nadvornikiana (Gyeln.) Brodo & D. Hawksw.
Bryoria nitidula (Th. Fr.) Brodo & D. Hawksw.
Bryoria oregana (Tuck. ex Willey) Brodo & D. Hawksw.
Bryoria simplicior (Vainio) Brodo & D. Hawksw.
Bryoria subcana (Nyl. ex Stizenb.) Brodo & D. Hawksw.
Bryoria tenuis (Dahl) Brodo & D. Hawksw.
Bryoria trichodes (Michx.) Brodo & D. Hawksw.
subsp. americana (Mot.) Brodo & D. Hawks.
subsp. trichodes

Buellia papillata (Sommerf.) Tuck.
Buellia punctata (Hoffm.) Massal.
Buellia spuria (Schaerer) Anzi

Caloplaca citrina (Hoffm.) Th. Fr.
Caloplaca exsecuta (Nyl.) Dalla Torre & Sarnth.
Caloplaca litoricola Brodo
Caloplaca pollinii (Massal.) Jatta

Candelariella canadensis Magn.

Cavernularia hultenii Degel.
Cavernularia lophyrea (Ach.) Degel

Cetraria californica Tuck.
Cetraria commixta (Nyl.) Th. Fr.
Cetraria cucullata (Bell.) Ach.
Cetraria ericetorum Opiz
Cetraria hepatizon (Ach.) Vainio
Cetraria islandica (L.) Ach.
Cetraria islandica (L.) Ach.
subsp. crispiformis (Räsänen) Kärnef.
Cetraria laevigata Rass.
Cetraria nigricans (Retz.) Nyl.
Cetraria nivalis (L.) Ach.
Cetraria subalpina Imsh.

Cetrelia alaskana (C. Culb. & Culb.) Culb. & C. Culb.
Cetrelia cetrarioides (Del. ex Duby) Culb. & C. Culb.

Chaenotheca chrysocephala (Turner ex Ach.) Th. Fr.
Chaenotheca stemonea (Ach.) Müll. Arg.

Chrysothrix chlorina (Ach.) Laundon

Cladina arbuscula (Wallr.) Hale & Culb. subsp. beringiana (Ahti) Golubk.
Cladina ciliata (Stirton) Trass f. tenuis (Flörke) Ahti
Cladina mitis (Sandst.) Hustich
Cladina portentosa (Duf.) Follm.
f. grisea
subsp. pacifica (Ahti) Ahti f. decolorans (Ahti) Ahti
Cladina rangiferina (L.) Nyl. subsp. rangiferina
Cladina stellaris (Opiz) Brodo
var. aberrans (des Abb.) Ahti
Cladina stygia (Fr.) Ahti

Cladonia alaskana Evans
Cladonia albonigra Brodo
Cladonia amaurocraea (Flörke) Schaerer
Cladonia asahinae Thoms.
Cladonia bacillaris Nyl.
Cladonia bacilliformis (Nyl.) Glück
Cladonia bellidiflora (Ach.) Schaerer
Cladonia borealis Stenroos
Cladonia cariosa (Ach.) Sprengel
Cladonia carneola (Fr.) Fr.
Cladonia cenotea (Ach.) Schaerer
Cladonia chlorophaea (Flörke) Spreng.
Cladonia coccifera (L.) Willd.
Cladonia coniocraea auct. (fide Ahti)
Cladonia cornuta (L.) Hoffm.
Cladonia crispata (Ach.) Flotow.
Cladonia cryptochlorophaea Asah.
Cladonia cyanipes (Sommerf.) Nyl.
Cladonia decorticata (Flörke) Sprengel
Cladonia deformis (L.) Hoffm.
Cladonia ecmocyna Leighton

subsp. ecmocyna
subsp. intermedia (Robb.) Ahti
Cladonia fimbriata (L.) Fr.
Cladonia furcata (Huds.) Schrader
Cladonia gracilis (L.) Wild.
subsp. gracilis
subsp. turbinata (Ach.) Ahti
subsp. vulnerata Ahti
Cladonia grayi Merr. ex Sandst.
Cladonia homosekikaica Nuno

Cladonia humilis (With.) Laundon
Cladonia kanewskii Oxner
Cladonia macrophylla (Schaerer) Stenh.
Cladonia macrophyllodes Nyl.
Cladonia macroptera Räsänen.
Cladonia maxima (Asah.) Ahti
Cladonia merochlorophaea Asah.
Cladonia metacorallifera Asah
Cladonia multiformis G. K. Merr
Cladonia nipponica Asah.
Cladonia ochrochlora Flörke
Cladonia phyllophora Ehrh. ex Hoffm.
Cladonia pleurota (Flörke) Schaerer
Cladonia pocillum (Ach.) O. Rich
Cladonia pyxidata (L.) Hoffm.
Cladonia ramulosa (With.) Laundon
Cladonia scabriuscula (Del. in Duby) Nyl.
Cladonia squamosa (Scop.) Hoffm.
Cladonia stricta (Nyl.) Nyl.
Cladonia subcervicornis (Vainio) Kernst.
Cladonia subfurcata (Nyl.) Arnold
Cladonia subsquamosa Krempelh.
Cladonia subulata (L.) Weber ex Wigg.
Cladonia sulphurina (Michx.) Fr.
Cladonia symphycarpa (Ach.) Fr.
Cladonia thomsonii Ahti
Cladonia transcendens (Vainio) Vainio
Cladonia umbricola Tønsb. & Ahti
    var. colombiana
    var. umbricola
Cladonia uncialis (L.) Weber ex Wigg.
Cladonia verruculosa (Vainio) Ahti

Coccotrema maritimum Brodo
Coccotrema pocillarium (Cumm.) Brodo

Coelocaulon aculeatum (Schreber) Link
Coelocaulon muricatum (Ach.) Laundon

Collema furfuraceum (Arnold) Du Rietz
Collema nigrescens (Huds) DC.

Dactylina arctica (Richardson) Nyl.

Dendriscocaulon intricatulum (Nyl.) Henssen

Dermatocarpon intestiformе (Körber) Hasse
Dermatocarpon miniatum (L.) Mann
Dermatocarpon rivulorum (Arnold) Dalla Torre & Sarnth.

Diplotomma alboatrum (Hoffm.) Flotow

Ephebe lanata (L.) Vain

Erioderma mollissimum (Samp.) Du Rietz

Farnoldia jurana (Schaerer) Hertel

Graphis scripta (L.) Ach.

Haematomma lapponicum Räsänen

Heterodermia speciosa (Wulfen) Trevisan

Hypogymnia apinnata Goward & McCune
Hypogymnia duplicata (Sm. ex Ach.) Rass.
Hypogymnia enteromorpha (Ach.) Nyl.
Hypogymnia inactiva (Krog) Ohlsson
Hypogymnia occidentalis Pike
Hypogymnia oceanica Goward
Hypogymnia physodes (L.) Nyl.
Hypogymnia tubulosa (Schaerer) Havaas
Hypogymnia vittata (Ach.) Parr

Hypotrachyna sinuosa (Sm.) Hale

Icmadophila ericetorum (L.) Zahlbr.

Imshaugia aleurites (Ach.) S. F. Meyer

Ionaspis epulotica (Ach.) Arnold

Lecanora circumborealis Brodo & Vitik.
Lecanora epibryon (Ach.) Ach.
Lecanora fuscescens (Sommerf) Nyl. in Norrlin
Lecanora grantii Magn.
Lecanora leptacina Sommerf.
Lecanora polytropa (Hoffm.) Rabenh.
Lecanora strobilina (Sprengel) Kieffer
Lecanora subrugosa Nyl.
Lecanora varia (Hoffm.) Ach.

Lecidella euphorea (Flörke) Hertel
Lecidella stigmatea (Ach.) Hertel & Leuck.

Lecidea cinnabarina Sommerf.
Lecidea lapicida (Ach.) Ach.
Lecidea shushanii Thomson

Lecidoma demissum (Rutstr.) G. Schneider & Hertel

Lepraria finkii (B. de Lesd. in Hue) R. C. Harris
Lepraria neglecta (Nyl.) Lettau

Leproloma cf. cacuminum (Massal.) Laundon
Leproloma diffusum v. chrysodeltoides Laundon
Leproloma vauauxii (Hue) Laundon

Leptogium burnetiae Dodge
Leptogium corniculatum (Hoffm.) Minks
Leptogium cyanescens (Rabenh.) Körber
Leptogium furfuraceum (Harm.) Sierk
Leptogium saturninum (Dicks.) Nyl.
Leptogium teretiusculum (Wallr.) Arnold

Lobaria hallii (Tuck.) Zahlbr.
Lobaria linita (Ach.) Rabenh.
Lobaria oregana (Tuck.) Mull. Arg.
Lobaria pulmonaria (L.) Hoffm.
Lobaria retigera (Bory) Trevisan
Lobaria scrobiculata (Scop.) DC. in Lam. & DC.

Lopadium pezizoideum (Ach.) Körber

Loxospora sp. nov. Imshaug & Brodo ined.

Massalongia carnosa (Dickson) Körber

Melanelia fuliginosa (Fr. ex Duby) Essl.

Melanelia multispora (A. Schneider) Essl.
Melanelia sorediata (Ach.) Goward & Ahti
Melanelia subaurifera (Nyl.) Essl.

Menegazzia terebrata (Hoffm.) Massal.
Micarea assimilata (Nyl.) Coppins
Micarea incrassata Hedl.

Mycobilimbia berengeriana (Massal.) Hafellner & V. Wirth
Mycoblastus affinis (Schaerer) Schauer
Mycoblastus alpinus (Fr.) Kernst.
Mycoblastus sanguinarius (L.) Norm

Neofuscelia subhosseana (Essl.) Essl.

Nephroma arcticum (L.) Torss.
Nephroma bellum (Spreng.) Tuck.
Nephroma helveticum Ach.
subsp. helveticum
subsp. sipeanum (Gyeln.) Goward & Ahti
Nephroma isidiosum (Nyl.) Gyeln.
Nephroma laevigatum Ach.
Nephroma parile (Ach.) Ach.
Nephroma resupinatum (L.) Ach.

Normandina pulchella (Borr.) Nyl.

Ocellularia sp. #1

Ochrolechia androgyna (Hoffm.) Arnold
Ochrolechia arborea (Kreyer) Almb.
Ochrolechia frigida (Sw.) Lynge
f. thelephoroides (Th. Fr.) Lynge
Ochrolechia juvenalis Brodo
Ochrolechia laevigata (Räsänen) Vers.
Ochrolechia oregonensis H. Magn.
Ochrolechia subpallescens Vers.

Ophioparma lapponica (Räsänen) Hafellner & R. W. Rogers

Pannaria ahlneri P. Jorg.
Pannaria laceratula Hue
Pannaria leucophaea (Vahl) P. Jorg.
Pannaria leucostictoides Ohls.
Pannaria pezizoides (Web.) Trevisan
Pannaria praetermissa Nyl. in Chyd. & Furuhj.
Pannaria saubineti (Mont.) Nyl.

Parmelia hygrophila Goward & Ahti
Parmelia kerguelensis Crombie
Parmelia omphalodes (L.) Ach.
Parmelia saxatilis (L.) Ach.
Parmelia squarrosa Hale
Parmelia sulcata Tayl.

Parmeliella triptophylla (Ach.) Müll. Arg.

Parmeliopsis ambigua (Wulfen in Jacq.) Nyl.
Parmeliopsis hyperopta (Ach.) Arnold

Parmotrema arnoldii (Du Rietz) Hale
Parmotrema chinense (Osbeck) Hale & Ahti

Peltigera aphthosa (L.) Willd.
blue-green phycosymbiodeme
Peltigera britannica (Gyeln.) Holtan-Hartwig & Tønsb.
Peltigera canina (L.) Willd.
Peltigera chionophila Goward ined.
Peltigera cinnamomea Goward ined.
Peltigera collina (Ach.) Schrader
Peltigera degenii Gyeln.
Peltigera didactyla (With.) Laundon
Peltigera elisabethae Gyeln.
Peltigera horizontalis (Huds.) Baumg.
Peltigera lepidophora (Nyl. ex Vainio) Bitter
Peltigera leucophlebia (Nyl.) Gyeln.
Peltigera membranacea Peltigera neckeri Hepp ex Müll. Arg.
Peltigera neopolydactyla (Gyeln.) Gyeln.
Peltigera pacifica Vitik.
Peltigera polydactyla (Neck.) Hoffm.
Peltigera ponojensis Gyeln.
Peltigera praetextata (Flörke ex Sommerf.) Zopf
Peltigera scabrosa Th. Fr.
Peltigera venosa (L.) Hoffm.

Pertusaria amara (Ach.) Nyl.
Pertusaria borealis Erichsen
Pertusaria cf. bryontha (Ach.) Nyl.
Pertusaria dactylina (Ach.) Nyl.
Pertusaria oculata (Dickson) Th. Fr.
Pertusaria ophthalmiza (Nyl.) Nyl.
Pertusaria subambigens Dibben

Phaeophyscia hirtella Essl.

Physcia adscendens (Fr.) H. Olivier
Physcia aipolia (Ehrh. ex Humb.) Furnr.
Physcia caesia (Hoffm.) Fürnr.
Physcia dubia (Hoffm.) Lett.
Physcia stellaris (L.) Nyl.
Physcia tenella (Scop.) DC. in Lam. & DC.

Physconia muscigena (Ach.) Poelt

Pilophorus acicularis (Ach.) Th. Fr.
Pilophorus clavatus Th. Fr.
Pilophorus nigricaulis Satô
Pilophorus robustus Th. Fr.

Placopsis gelida (L.) Linds.

Placynthium nigrum (Huds.) Gray

Platismatia glauca (L.) Culb. & Culb.

Platismatia herrei (Imsh.) Culb. & C. Culb.
Platismatia lacunosa (Ach.) Culb. & Culb.
Platismatia norvegica (Lynge) Culb. & C. Culb.

Polychidium dendriscum (Nyl.) Henssen or cf. contortum Henssen

Porpidia carlottiana Gowan
Porpidia flavicunda (Ach.) Gowan
Porpidia flavocaerulescens (Hornem.) Hertel & Schwab
Porpidia speirea (Ach.) Krempelh.
Porpidia thomsonii Gowan

Pseudephebe minuscula (Nyl. ex Arnold) Brodo & D. Hawksw.
Pseudephebe pubescens (L.) Choisy

Pseudocyphellaria anomala Brodo & Ahti
Pseudocyphellaria anthraspis (Ach.) Magn.
Pseudocyphellaria crocata (L.) Vainio
Pseudocyphellaria rainierensis Imsh.

Psora decipiens (Hedwig) Hoffm.

Psoroma hypnorum (Vahl) S. F. Gray

Ramalina dilacerata (Hoffm.) Hoffm.
Ramalina farinacea (L.) Ach.
Ramalina inflata (J. D. Hook & Taylor) J. D. Hook & Taylor
Ramalina cf. leptocarpha
Ramalina menziesii Taylor
Ramalina roesleri (Hochst. ex Schaerer) Hue
Ramalina thrausta (Ach.) Nyl.

Rhizocarpon badioatrum (Flörke ex Sprengel) Th. Fr.
Rhizocarpon copelandii (Körber) Th. Fr.
Rhizocarpon eupetraeoides (Nyl.) Blomb. & Forss.
Rhizocarpon geminatum Körber
Rhizocarpon geographicum (L.) DC.
Rhizocarpon hochstetteri (Körber) Vainio
Rhizocarpon praebadium (Nyl.) Zahlb.
Rhizocarpon superficiale (Schaerer) Vainio

Rhizoplaca chrysoleuca (Sm.) Zopf

Siphula ceratites (Wahlenb.) Fr.

Solorina bispora Nyl.
Solorina crocea (L.) Ach.

Sphaerophorus fragilis (L.) Pers.
Sphaerophorus globosus (Huds.) Vainio
var. gracilis (Müll. Arg.) Zahlbr.
Sphaerophorus melanocarpus (Sw.) DC. in Lam & DC.

Stereocaulon alpinum Laur. ex Funck
Stereocaulon arenarium (Savicz) Lamb
Stereocaulon botryosum Ach.
Stereocaulon capitellatum Magnusson
Stereocaulon condensatum Hoffm.
Stereocaulon coniophyllum Lamb
Stereocaulon dactylophyllum Flörke
Stereocaulon glareosum (Savicz) Magn.
Stereocaulon grande (H. Magn.) H. Magn.
Stereocaulon groenlandicum (Dahl) Lamb
Stereocaulon intermedium (Savicz) Magn.
Stereocaulon octomerum Mull. Arg.
Stereocaulon paschale (L.) Hoffm.
Stereocaulon pileatum Ach.
Stereocaulon rivulorum Magn.
Stereocaulon saviczii Du Rietz
Stereocaulon saxatile Magnusson
Stereocaulon spathuliferum Vainio
Stereocaulon sterile (Savicz) Lamb ex Krog
Stereocaulon subcoralloides (Nyl.) Nyl.
Stereocaulon symphycheilum Lamb
Stereocaulon tomentosum Fr.
Stereocaulon vesuvianum Pers.

Sticta fuliginosa (Hoffm.) Ach.
Sticta limbata (Sm.) Ach.
Sticta weigelii (Ach.) Vainio
Sticta wrightii Tuck.

Tephromela aglaea (Sommerf.) Hertel & Rambold

Thamnolia subuliformis (Ehrh.) Culb.
Thamnolia vermicularis (Sw.) Ach. ex Schaerer

Thelotrema lepadinum (Ach.) Ach.

Toninia tristis (Th. Fr.) Th. Fr.

Tremolecia atrata (Ach.) Hertel

Tuckermannopsis chlorophylla (Willd. in Humb.) Vainio

Umbilicaria angulata Tuck.
Umbilicaria arctica (Ach.) Nyl.
Umbilicaria deusta (L.) Baumg.
Umbilicaria hyperborea (Ach.) Hoffm.
Umbilicaria proboscidea (L.) Schrader
Umbilicaria torrefacta (Lightf.) Schrader
Umbilicaria virginis Schaerer

Usnea ceratina Ach.
Usnea filipendula Stirton
Usnea fragilescens Hav. ex Lynge (sensu Brodo)
Usnea hirta (L.) Weber ex Wigg.
Usnea lapponica Vainio
Usnea longissima Ach.
Usnea scabiosa Mot.
Usnea scabrata Nyl.
subsp. nylanderiana Mot.
Usnea subfloridana Stirton
Usnea trichinella Mot.
Usnea trichodea Ach.

Verrucaria maura Wahlenb in Ach.

Vestergrenopsis isidiata (Degel.) Dahl

Xanthoria candelaria (L.) Th. Fr.
Xanthoria elegans (Link) Th. Fr.

Xanthoria fallax (Hepp in Arnold) Arnold
Xanthoria polycarpa (Hoffm.) Rieber
Xanthoria sorediata (Vainio) Poelt.

3.32 Air pollution sensitivity of the lichens of the Tongass National Forest

The sensitivities of lichens to air pollution in southeastern Alaska have not been directly determined. **Fig. 21** is a compilation of literature reports which have documented sensitivities of lichens known from this inventory to occur on the Tongass National Forest. Sensitivity categories used in **Fig. 21** are explained below:

SO_2 Sensitivity: Published limits of presence and absence, when available, are given in $\mu g/m^3$. Most values are based on averages of several studies for one or more years but some are partly based on average winter concentrations over several years. Numbers before the slash are for presence limits. Numbers after the slash indicate published limits of absence. In some cases one or the other may be unknown. In other cases different authors do not agree on the sensitivity and a range was given or some records were not included. The information comes from Wetmore (1983). Lichens are categorized as follows:
Sensitive = present at average annual ambient SO_2 levels below 50 $\mu g/m^3$
Intermediate = present at average annual ambient SO_2 levels up to 50-100 $\mu g/m^3$
Tolerant = present at average annual ambient SO_2 levels greater than 100 $\mu g/m^3$.

General sensitivity to air pollution: Sensitivity to air quality is given on a 1 to 10 scale. One is highly tolerant and 10 is highly sensitive. These estimates are based on a literature survey of 54 field studies of lichen sensitivity around various point sources in the former Soviet Union, Europe, Canada and the United States (Insarova et al., 1992). Although the authors standardized methods to compare the independent studies, variation in sensitivity for the same lichen species in different studies is considerable. The variation probably stems from differences in climate, relative concentration and composition of pollutants and substrate differences as well as differences due to subjective elements in compiling the various studies and within the studies themselves.

Of the lichens listed in **Fig. 21**, the following are both sensitive and common, making them useful indicators of air quality: *Bryoria bicolor, B. trichodes, Cladonia fimbriata, Hypogymnia tubulosa, H. vittata, Lecidea cinnabarina, Leptogium cyanescens, L. saturninum, Lobaria oregana, L. pulmonaria, Menegazzia terebrata, Nephroma bellum, N. helveticum, N. parile, Peltigera collina, Sticta fuliginosa,* and *Usnea longissima.* In general, the fruticose and nitrogen fixing epiphytic lichens are most sensitive to air pollution, followed by the moderately sensitive non-nitrogen fixing foliose lichens and lichens growing on soil and other protected habitats (e.g. Hawksworth and Rose, 1970). The most tolerant lichens are often crustose forms. With the exception of certain localized areas close to Sitka and Ketchikan, epiphytic nitrogen fixing lichens and pendent fruticose lichens were abundant in forested areas throughout the Tongass National Forest, a sign of very good regional air quality. Although the

Figure 21. Air pollution sensitivity of Tongass National Forest lichens.

Sensitivity Category	Lichen	SO_2 Sensitivity presence/absence in $\mu g/cm^3$*	General Sensitivity**
SENSITIVE	*Bryoria bicolor*		10
	Bryoria chalybeiformis		7-9
	Bryoria lanestris		9
	Bryoria nadvornikiana		10
	Bryoria trichodes	13-26/26-52	9
	Cladonia fimbriata	13/13-26	5.7-10
	Hypogymnia tubulosa	10-30/-	2-8
	Hypogymnia vittata		8
	Lecidea cinnabarina	26-34/34-52	
	Leptogium cyanescens		10
	Leptogium saturninum		6-10
	Lobaria oregana	-/50-70	
	Lobaria pulmonaria	26/26-34	7-10
	Lobaria scrobiculata		10
	Melanelia subaurifera	10-30/-	
	Menegazzia terebrata		10
	Mycoblastus alpinus		8
	Nephroma bellum		6-9
	Nephroma helveticum		8
	Nephroma parile		8
	Normandina pulchella	35/50	7.8-8.6
	Ochrolechia androgyna	26-34/34-52	9
	Ochrolechia arborea		8
	Parmelia omphalodes		8.5
	Parmelia squarrosa	26-39/40	
	Parmeliellatriptophylla		8
	Peltigera canina		8.6-10
	Peltigera collina		6-10
	Ramalina farinacea		5-9.2
	Ramalina roesleri		8.
	Ramalina thrausta		9
	Sticta fuliginosa		10
	Sticta limbata		8.6-10
	Thelotrema lepadinum		
	Tuckermannopsis chlorophylla	10-30/-	2-10
	Usnea ceratina	35/-	7.8-9.1
	Usnea filipendula	10-30/-	6-10
	Usnea hirta	30-80/-	5-10
	Usnea longissima		8.6-10
INTERMEDIATE	*Usnea subfloridana*	40/-	6-10
	Alectoria sarmentosa	34-52/52-78	7-9.
	Bryoria capillaris	52-78/-	5.7-9
	Bryoria fuscescens	60/70	5.5-10
	Chrysothrix chlorina		7
	Cladonia coniocraea	34-52/52-78, 23	1.6-5.7
	Cladonia squamosa		4.5-5.7
	Diplotomma alboatrum		4.4
	Graphis scripta	10/30/65	7-8
	Heterodermia speciosa		4-6
	Hypogymnia physodes	52-70/78	0.6-7.1
	Imshaugia aleurites	10/65	
	Lecanora subrugosa	30-80/-	6-7
	Lecanora varia		4-5.7
	Lecidella euphorea		4-8
	Lecidella euphorea		4-8
	Lopadium pezizoideum	34-52/52-78	
	Melanelia fuliginosa	34-52/52-78	
	Mycoblastus affinis	34-52/52-78	
	Mycoblastus sanguinarius	52-78/-	5-10
	Nephroma laevigatum	-/65	8-8.6
	Parmelia saxatilis	34-52/52-78	1.7-8.9
	Parmelia sulcata	52-100/95	1.8-8.9
	Parmeliopsis ambigua	52-65/78	1.2-8.9
	Parmeliopsis hyperopta	52-78/-	8-9.4
	Peltigera horizontalis	-/65	
	Pertusaria amara		4-8.9
	Physcia adscendens	50-80/90	2-6.7
	Physcia aipolia	26-50/65	4-10
	Physcia caesia		5.6-8.7
	Physcia tenella	60/70	1.7-7.1
	Platismatia glauca	52-78/-	1.7-9.2
	Ramalina dilacerata	34-52/52-78	
	Xanthoria candelaria	60/70	4
	Xanthoria polycarpa	13-50/60	2-10
TOLERANT	*Buellia punctata*	90-110/125	1.1-5.6
	Lepraria finkii		
	Physcia dubia	90-110/125	1.2-4.4
	Stereocaulon pileatum		

* values before and after the slash indicate average annual atmospheric SO_2 concentrations (in ug/m3) tolerated and not tolerated by the lichen, respectively. From Wetmore (1983).
** From a scale devised by Insarova et al. (1992). See text. 10 is most sensitive.

specific sensitivities of the most common lichens of the Forest (**Fig. 22**) are largely unknown, suggestions for remedying this problem are made in Section 4 (Recommendations).

3.33 Most common lichens of the Tongass National Forest

A list of the most common non-crustose species of the Tongass National Forest, with equal influence given to spruce, hemlock, cedar, alder, cottonwood, willow, mixed conifer, shorepine, subalpine, alpine and glacier lichen communities is given in **Fig. 22**:

Figure 22. Most common macrolichens of the Tongass National Forest.

1. *Alectoria sarmentosa ssp. sarmentosa*
2. *Bryoria trichodes ssp americana*
3. *Cavernularia hultenii*
4. *Cladina rangiferina ssp. rangiferina*
5. *Cladonia bellidiflora*
6. *Cladonia squamosa*
7. *Hypogymnia duplicata*
8. *Hypogymnia enteromorpha*
9. *Lobaria linita*
10. *Lobaria oregana*
11. *Parmelia sulcata*
12. *Peltigera britannica*
13. *Platismatia glauca*
14. *Platismatia herrei*
15. *Platismatia lacunosa*
16. *Platismatia norvegica*
17. *Sphaerophorus globosus var. gracilis*

This list was determined by calculating the percentage of plots in which each lichen species was present within each plant community and performing a cluster analysis which separated 325 lichens into two groups (this list, and all others). These lichens are typical species of most Pacific Northwest and North Northwest coastal coniferous forests, although, *Hypogymnia duplicata, Platismatia lacunosa and P. norvegica* become quite uncommon by southern Washington.

3.4 Lichen Community Analyses

3.41 Variables affecting lichen species composition

General patterns of lichen species distribution as affected by three important environmental variables: elevation, vegetation type, and amount of light, were examined. No attempt is made here to describe lichen communities of microhabitats (i.e. communities specific to downed logs, crevices of snags, tree boles, etc.). In our analysis, vegetation type and elevation were the best predictors of lichens expected within a macrosite (e.g. a 42' radius circle). The most distinct species compositions were seen between very low (<5'), intermediate (5-1700'), high (1700-3000') and very high (>3000') elevations and between beach/riparian areas, shorepine muskegs, other forested communities, subalpine, alpine and recently glaciated areas.

Many factors combine to make a given habitat suitable for individual lichen species. Temperature and humidity cycles of microsites for example, can be very important (McCune, 1992). In southeastern Alaska humidity and temperature fluctuations, are greatly moderated by frequent precipitation, the large number of overcast days, the mountain barrier to continental climate influences, and the proximity to stabilizing marine air and ocean currents. The availability of water within a site, or from site to site at the same elevation, is usually not as extreme as in coniferous forests further south or inland. Hypothetically, light could be more limiting than water in some vegetated areas of southeastern Alaska. The relatively wet environment of open areas allows some lichens typical of closed forests in more southerly areas to grow in exposed locations in southeastern Alaska. Other factors such as forest age, substrate (type and continuity), and disturbance regime (intensity, size and frequency) are also important as many lichens are slow to disperse or require substrates which only occur in older forests (Hyvärinen et al., 1992; Tibell, 1992). This study focused primarily on climax communities with high temporal and spatial continuity of substrate and few human caused dispersal limitations. Fire, a major source of disturbance in other areas, is uncommon in southeastern Alaska ecosystems (Martin, 1989).

3.42 Relationship of lichen species composition to canopy cover

Overstory canopy cover was measured because of its relationship to the amount of light available to lichens growing under the canopy and near the forest floor. As photosynthetic organisms, lichens must have light to grow, even though maximum photosynthetic rate can often be reached at light levels far below those needed to saturate photosynthetic systems of higher plants.

Cluster and multi-dimensional scaling analyses (**Fig. 25** and **26**) produced three groups of canopy ranges with similiar lichen species composition: low (5-30% cover), medium (35-50% cover), and high (55-95% cover). Lichens which were the most important determinants of these clusters are listed in **Fig. 24**. (Statistical significance was determined by analysis of variance and when $p < 0.05$, lichens were boldfaced in the table.) The primary lichens associated with high canopy cover plots were several lichens of downed, mossy logs and tree boles: *Cladonia coniocraea, Peltigera britannica, P neopolydactyla* and *P. scabrosa*. The lichens which were most abundant under medium canopy cover conditions were: *Bryoria cervinula, B. tenuis, B. trichodes, Cladonia cornuta, C. deformis, C. macroptera, C. ochrochlora, C. umbricola, Hypogymnia tubulosa, Lobaria oregana, Nephroma helveticum, Parmeliopsis ambigua, Peltigera collina, P. membranacea, Ramalina farinacea* and *R. roesleri.* Of these, all except the *Cladonia* species and *P. membranacea*, are epiphytic. Lichens with highest constancy under low canopy cover conditions were *Bryocaulon pseudosatoanum, Bryoria bicolor, B. glabra, Cladina arbuscula, C. portentosa, Cladonia maxima, C. umbricola, Hypogymnia inactiva, H. oceanica, Parmeliopsis hyperopta* and *Siphula ceratites*. All of these are epiphytic except the *Cladina* species and *Cladonia maxima*, which grow in muskegs (peatbogs), often on brushy hummocks, and *Siphula ceratites*, which is an aquatic lichen of muskeg pools.

The division of lichen species into three distinct light regimes is interesting, but appears to be the result of the habitat requirements of a small percentage of lichens, mentioned above. Some of the species significantly correlated with low canopy cover in southeastern Alaska, e.g. *H. inactiva* and *Parmeliopsis hyperopta* are usually found under much higher canopy cover conditions in more southern parts of the Pacific Northwest where moisture and temperature extremes may be more limiting and light perhaps less limiting. The fact that correlations of total species lists between different canopies covers (**Fig. 23**) was always $\geq$ 0.7 indicates however that most species can be found in a wide range of light regimes in southeastern Alaska.

Figure 23. Correlation between lichen species compositions in forests of varying canopy cover.

Pearson correlation matrix

% Canopy Cover:

	5-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-95
5-10	1.000000								
11-20	0.912455	1.000000							
21-30	0.910688	0.898226	1.000000						
31-40	0.832121	0.837436	0.827442	1.000000					
41-50	0.823378	0.822772	0.828278	0.865647	1.000000				
51-60	0.728447	0.752353	0.742005	0.809163	0.816762	1.000000			
61-70	0.737252	0.712661	0.714784	0.819651	0.802644	0.819188	1.000000		
71-80	0.747705	0.754378	0.743565	0.819553	0.821136	0.881937	0.890247	1.000000	
81-95	0.709794	0.705309	0.695848	0.801231	0.754698	0.836786	0.870293	0.916080	1.000000

Number of observations: 312
Bartlett chi-square statistic: 4099.175 df= 36 prob=0.00
The Bonferroni probability test showed no significant differences between lichen communities of any canopy cover.

Figure 24. Effect of canopy cover on lichen constancy.

	Species Constancy								
Overstory canopy cover (%):	10	20	30	40	50	60	70	80	95
Lichens encountered most frequently on HIGH (60-95%) canopy cover plots.									
Cavernularia lophyrea	16	19	19	25	33	11	42	43	43
Cladonia coniocraea	0	4	0	0	25	11	25	26	21
Cladonia grayii	0	0	6	0	0	11	8	0	0
Hypogymnia appinata	0	0	6	0	8	11	0	13	7
Hypogymnia physodes	5	4	6	0	0	22	8	4	0
Lobaria linita	32	38	19	25	42	44	50	57	21
Lobaria retigera	0	4	0	0	8	0	8	9	0
Nephroma laevigata	0	4	0	0	0	11	8	4	0
Normandina pulchella	5	0	0	0	0	11	0	4	0
Ochrolechia oregonensis	0	0	0	0	8	0	8	9	0
Parmeliopsis hyperopta	16	8	6	13	8	22	25	4	7
Peltigera britannica	5	0	13	38	17	44	58	30	14
Peltigera neopolydactyla	0	15	6	25	17	33	33	35	36
Peltigera praetextata	0	0	0	0	8	0	17	0	0
Peltigera scabrosa	5	4	0	13	25	22	33	30	36
Platismatia lacunosa	26	23	50	25	25	56	25	61	57
Pseudocyphellaria anomola	5	0	0	0	17	0	33	9	7
Stereocaulon grande	0	0	0	0	0	11	8	0	0
Sticta fuliginosa	0	0	0	0	8	11	17	4	0
Sticta weigelli	0	0	0	0	8	0	17	4	0
Tuckermanopsis chlorophylla	0	0	0	13	8	0	8	22	14
Usnea longissima	5	19	13	25	8	33	33	13	36
Lichens encountered most frequently on LOW (0-39%) canopy cover plots.									
Bryocaulon pseudosatoanum	37	35	38	13	33	22	8	4	0
Bryoria bicolor	21	42	50	25	8	11	17	9	0
Bryoria carlottae	0	23	38	13	25	0	0	0	0
Bryoria glabra	32	19	25	13	17	0	8	4	14
Cavernularia hultenii	58	50	63	63	50	33	50	48	43
Cetraria californica	16	15	0	0	8	0	0	4	0
Cetraria islandica	11	15	0	0	8	0	0	0	0
Cladina arbuscula	53	77	50	38	33	11	8	4	0
Cladina portentosa	21	12	13	13	8	11	0	4	0
Cladonia decorticata	47	15	31	13	33	22	0	9	0
Cladonia gracilis	16	15	13	0	17	11	0	4	7
Cladonia maxima	37	54	44	63	17	11	0	4	0
Cladonia sulphurina	21	12	6	13	8	0	8	4	0
Cladonia umbricola	26	35	38	25	17	0	0	0	0
Coelocaulon aculeatum	0	8	6	0	8	0	0	0	0
Hypogymnia inactiva	26	27	38	13	17	0	8	4	14
Hypogymnia oceanica	32	23	44	25	33	11	17	4	0
Nephroma parile	5	12	13	13	0	0	8	9	7
Ochrolechia laevigata	11	19	6	0	17	11	0	4	7
Parmelia saxatilis	32	27	50	25	25	56	8	13	14
Parmeliopsis hyperopta	26	19	31	25	17	11	17	9	14
Siphula ceratites	16	19	13	0	8	0	0	0	0

	Species Constancy								
Overstory canopy cover (%):	10	20	30	40	50	60	70	80	95
Lichens encountered most frequently on MEDIUM (40-59%) canopy cover plots.									
Bryoria cervinula	11	12	13	25	8	0	0	0	0
Bryoria fuscesens	5	0	6	0	8	0	0	0	0
Bryoria lanestris	0	4	13	0	25	0	0	0	0
Bryoria oregana	5	0	0	0	8	0	0	0	0
Bryoria tenuis	26	12	44	50	50	0	8	17	0
Bryoria trichodes	74	69	69	75	100	56	58	35	29
Cetraria subalpina	0	12	0	0	17	0	0	0	0
Cladina ciliata	0	8	6	13	0	0	0	0	0
Cladonia bellidiflora	58	50	56	63	58	67	50	52	21
Cladonia chlorophaea	11	0	6	13	0	0	17	0	0
Cladonia cornuta	26	31	38	50	67	22	42	22	21
Cladonia deformis	5	15	6	13	17	0	0	9	0
Cladonia fimbriata	5	12	13	25	17	0	42	4	7
Cladonia furcata	16	4	6	25	0	11	8	4	0
Cladonia macroptera	0	0	0	25	8	0	0	0	0
Cladonia ochrochlora	11	0	6	50	25	22	33	26	43
Cladonia scabriuscula	0	4	19	25	8	0	17	4	0
Cladonia sp. #2	11	8	0	13	17	11	8	9	7
Cladonia transcendens	0	0	0	0	17	11	0	4	7
Cladonia umbricola	16	15	13	38	42	33	17	13	14
Hypogymnia duplicata	26	54	44	63	33	56	25	39	43
Hypogymnia tubulosa	0	0	0	13	17	11	0	4	0
Hypoymnia enteromorpha	32	73	44	63	67	89	42	65	50
Lobaria oregana	5	31	13	50	42	44	33	57	43
Lobaria pulmonaria	11	12	13	13	17	0	17	17	7
Loxospora sp. nov.	11	15	6	25	0	0	0	0	7
Mycoblastus sanguinarius	16	15	0	25	17	0	8	4	14
Nephroma bellum	11	15	19	25	25	11	25	9	21
Nephroma helveticum	5	8	6	25	25	11	17	0	14
Nephroma retigera	11	8	0	13	0	0	8	4	7
Pannaria saubinetti	5	0	0	13	0	11	0	4	0
Parmelia sulcata	21	42	25	50	50	44	25	22	14
Parmeliopsis ambigua	5	8	0	13	8	0	0	0	0
Peltigera collina	0	0	0	13	17	11	0	4	7
Peltigera membranacea	5	0	6	38	25	22	33	22	29
Peltigera pacifica	0	0	0	13	8	11	17	9	0
Peltigera polydactyla	5	15	0	25	8	22	17	9	14
Platismatia glauca	79	77	69	88	83	78	75	87	86
Platismatia herreii	63	73	38	88	50	56	50	43	57
Psoroma hypnorum	0	4	0	0	8	11	0	0	0
Ramalina farinacea	0	0	0	13	17	0	0	9	0
Ramalina roesleri	0	0	6	13	25	0	0	9	0

Figure 25. Similarities of lichen species compositions across a range of overstory canopy cover (%). Tree Diagram.

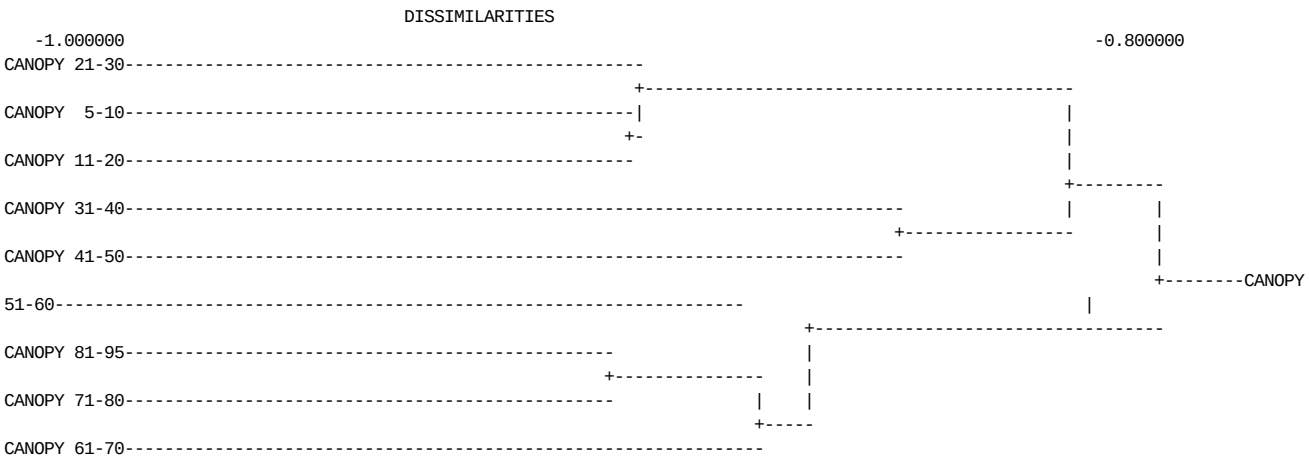
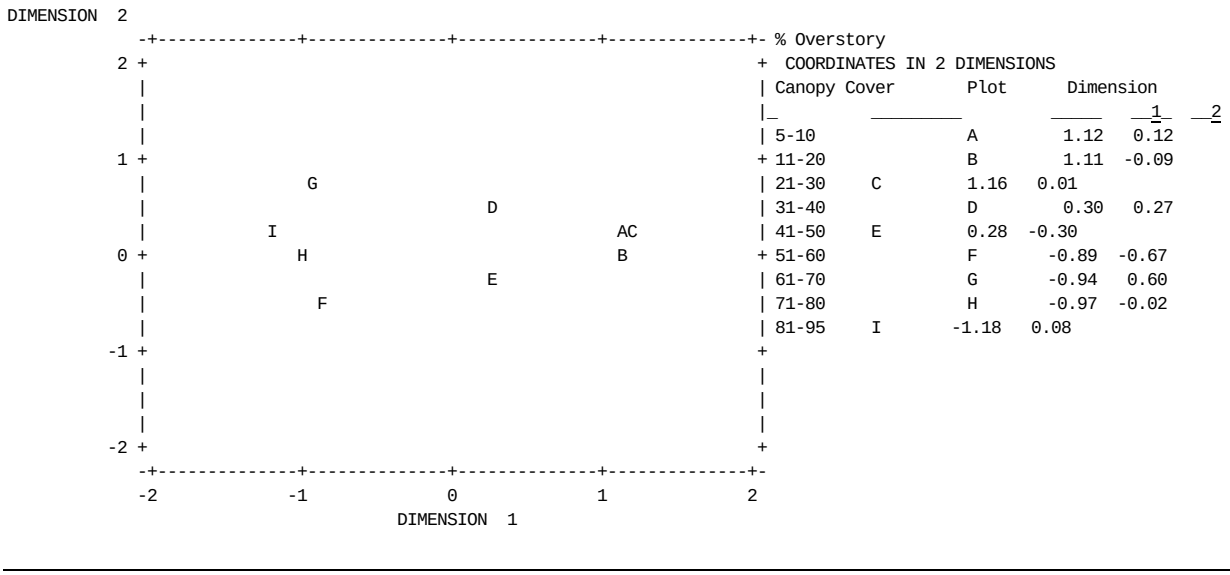


Figure 26. Similarities of lichen species compositions across a range of overstory canopy cover (%). Multidimensional scaling model.



3.42 Relationship of elevation to lichen species composition

Elevation is an important environmental factor because of its effects on average temperatures. In combination with orographic effects, temperature influences moisture availability, associated vegetation, and metabolic rates of lichens. Although lichens and mosses are metabolically active and fully photosynthetic at temperatures far below optimum for vascular plants, temperatures must be above freezing for lichens to become physiologically active. Similarly the additional moisture at high elevations is not always available for metabolism since lichens are frozen for longer time periods.

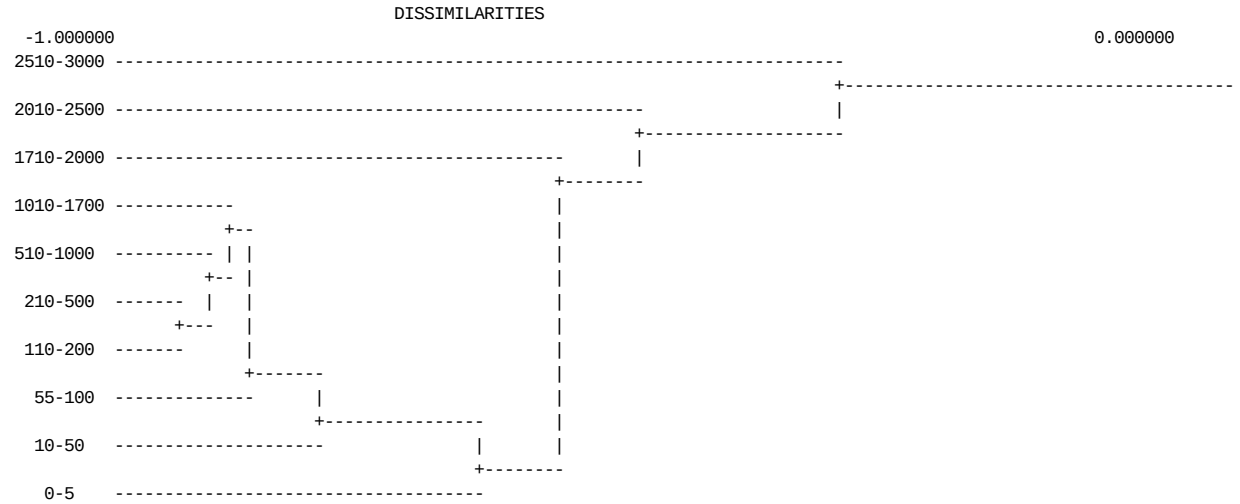
Cluster and multi-dimensional scaling analyses (**Figs. 28** and **29**) grouped lichen species lists from elevations between 200 and 1700 feet (the non-riparian, non-beach edge, low elevation coniferous forests and muskegs). The elevations with the next closest lichen species compositions were the 100-190 feet and 50-95 feet ranges. These lower elevations would include many riparian areas, some with deciduous substrates. The 5-10 foot elevational range comprise the beach communities, the remaining riparian areas, and the distinct glacier terminus communities. At the other extreme, the three highest elevations did not cluster but were distinct and graded with elevation away from the next closest elevations. The Bonferroni probabilities indicated statistically significant differences between the alpine and all other elevations. Taking this into consideration and looking at the strong differences between species composition at different elevations in the correlation matrix (**Fig. 27**) the general pattern which emerges is that some lichens occured at distinct elevations within the alpine and subalpine, many could be found from sea level to 1700 feet, and others were found primarily at elevations below 50 feet.

Figure 27. Correlation between lichen species compositions at various elevations in southeastern Alaska.

Elevation:	4000	3000	2500	1700	1000	500	200	100	50	5
3010-4000	1.000									
2510-3000	0.371	1.000								
1710-2500	0.349	0.506	1.000							
1010-1700	0.097	0.616	0.549	1.000						
510-1000	0.087	0.520	0.485	0.897	1.000					
210-500 0.064	0.552	0.510	0.901	0.921	1.000					
110-200 0.047	0.551	0.442	0.876	0.910	0.939	1.000				
55-100	0.057	0.485	0.404	0.784	0.806	0.877	0.882	1.000		
10-50	0.011	0.447	0.388	0.651	0.664	0.745	0.795	0.825	1.000	
0-5	-0.088	0.199	0.173	0.459	0.524	0.537	0.632	0.652	0.689	1.000

Number of observations: 312
Bartlett chi-square statistic= 3399.331 df=45 prob= 0.000
Significant correlations (Bonferroni probability test values >0.8) were observed for correlation values > 0.1.

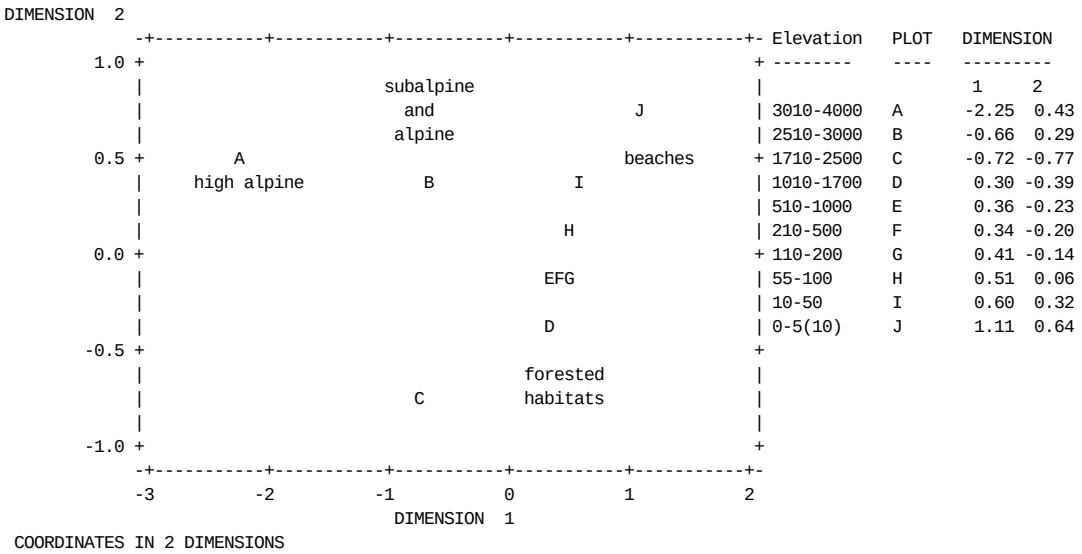
Figure 28. Similarities of lichen species composition across a range of elevations (ft). Tree diagram.



3.43 Relationship of dominant vegetation types to lichen species composition

Examining lichen species composition within vegetation types more closely (**Figs. 30-32**), we found that western hemlock and western hemlock-yellow cedar lichens were highly similar and that the next most similar habitats were the mixed conifer and shorepine communities. Lichen species composition of spruce stands was intermediate between these forested communities and other riparian communities (alder, cottonwood and willow). Mountain hemlock communities of the subalpine had a lichen species composition intermediate between the coniferous communities and the alpine and glacier communities.

Figure 29. Similarities of lichen species composition across a range of elevations (ft). Multidimensional scaling model.



The lichens of alpine and glacier terminus communities were most similar to each other. Although the lichen species lists from each habitat appeared biologically distinct (discussed below), analysis of variance indicated that only the alpine and glacier termini habitats were statistically different from all the rest, and the willow habitats were different from the mountain hemlock plots. Since the statistical treatment includes presence/absence frequencies of all lichens found within each type of habitat, one sees a slurring effect of the 20 or so most common lichen species which have very adaptable habitat

Figure 30. Correlation between lichen species compositions of dominant vegetation types in southeastern Alaska.

Pearson Correlation Matrix

	TSHE	CHNO	PISI	ALNUS	MXCON	TSME	PICO	POTR	SALIX	ALPINE	GLACIER
TSHE 35	1.000										
CHNO 6	0.866	1.000									
PISI 33	0.828	0.720	1.000								
ALNUS 15	0.538	0.470	0.666	1.000							
MXDCON 15	0.850	0.826	0.699	0.462	1.000						
TSME 11	0.653	0.639	0.547	0.339	0.711	1.000					
PICO 62	0.747	0.719	0.561	0.392	0.811	0.688	1.000				

POTR 14	0.309	0.229	0.545	0.572	0.203	0.193	0.142	1.000			
SALIX 7 0.245	0.137	0.457	0.536	0.161	0.141	0.105	0.762	1.000			
ALPINE 8	0.039	0.053	-0.022	-0.080	0.063	0.335	0.062	-0.076	-0.090	1.000	
GLACIER 5	0.049	0.126	-0.004	0.030	0.106	0.255	0.079	-0.029	-0.071	0.292	1.000

Number of observations: 312
Bartlett chi-square statistic: 2589.902 df= 55 prob= 0.000
Significant correlations (Bonferroni probability test values > 0.8) were observed for correlation values > 0.15.
Number following plant series names indicates the quantity of plots sampled.

Key to plant series/habitat acronyms:

TSHE= *Tsuga heterophylla* plant series
CHNO= *Tsuga heterophylla/Chamaecyparis nootkatensis* plant series
PISI= *Picea sitchensis* plant series
ALNUS= *Picea sitchensis/Alnus sinuata* plant assoc.
MXDCON= Mixed conifer plant series
PICO= *Pinus contorta* plant series
TSME= *Tsuga mertensiana* plant series
POTR= *Populus trichocarpa* plant series
SALIX= *Salix* dominated riparian habitats
ALPINE= non-forested habitats with elevations > 2500 feet.
GLACIER= non-forested habitats in the vicinity of glacier termini.

Figure 31. Similarities between lichen species compositions of dominant vegetation types in southeastern Alaska. (Key to plant SERIES acronyms same as **Fig. 4**.) Tree diagram.

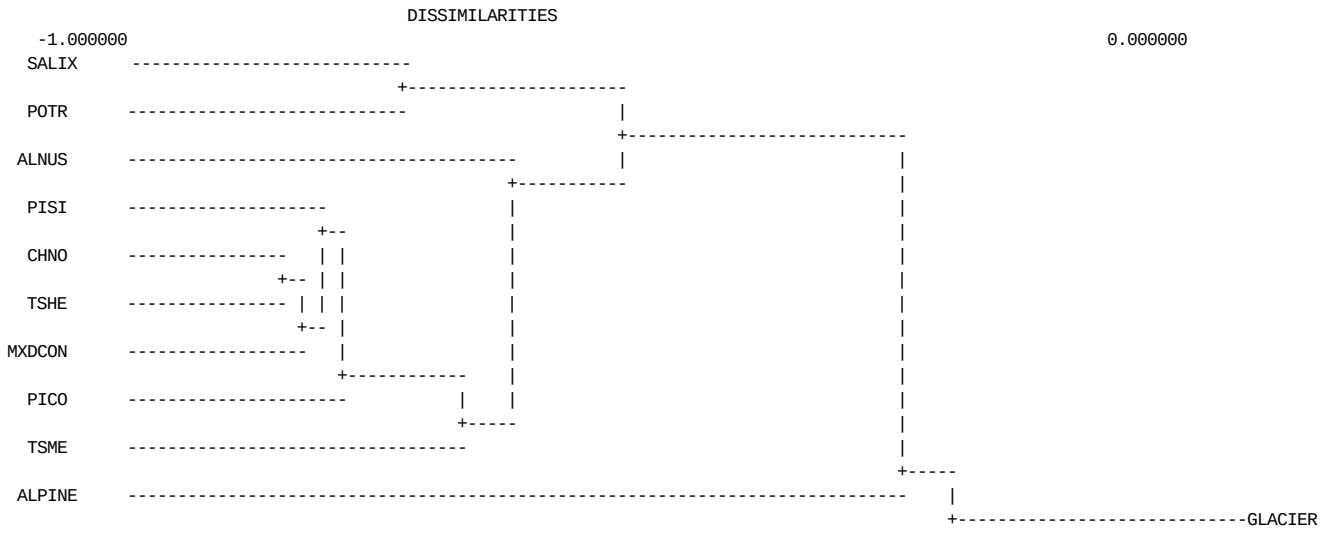
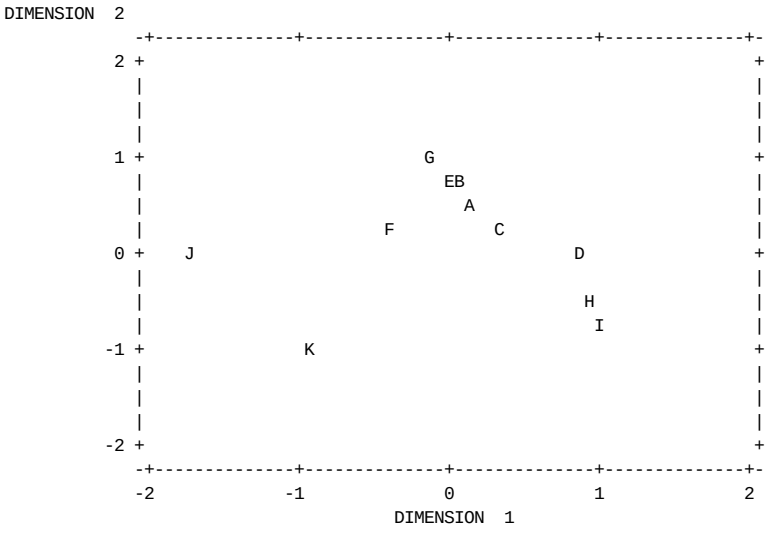


Figure 32. Similarities between lichen species compositions of dominant vegetation types in southeastern Alaska. (Key to plant SERIES acronyms same as **Fig. 4**.) Multi-dimensional scaling model.



COORDINATES IN 2 DIMENSIONS

SERIES	PLOT	DIMENSION 1	DIMENSION 2
TSHE	A	0.14	0.45
CHNO	B	0.09	0.56
PISI	C	0.33	0.25
ALNUS	D	0.85	-0.03
MXDCON	E	-0.03	0.61
TSME	F	-0.43	0.23
PICO	G	-0.15	0.76
POTR	H	0.93	-0.59
SALIX	I	1.00	-0.86
ALPINE	J	-1.76	-0.20
GLACIER	K	-0.96	-1.16

requirements and can be found in most of the vegetation types. The very infrequently occurring lichens with specific habitat requirements (for example specific to a microsite or a single rock type or finer subdivision of plant habitat) are not occurring often enough to be statistically correlated with any dominant vegetation type. Therefore the statistical differences are mainly a reflection of species with intermediate to common frequency and habitat requirements met by conditions within specific vegetation types.

Despite the artificiality of this grouping system, it is very interesting to note that similarities between lichen species composition from vegetation type to vegetation type very closely follows the similarity of these vegetation types to each other. In other words, western hemlock and western hemlock-yellow cedar are the most closely related plant series. The mixed conifer plant series is intermediate to western hemlock and shorepine series, etc.

3.44. Lichen species composition of typical vegetation types in southeastern Alaska.

Typical lichen species (occuring in >= 10% of plots) from each of the dominant vegetation types are presented in **Fig. 33**. Among forested communities, the spruce and spruce-alder riparian communities had the greatest species richness, followed by the remaining coniferous communities, and the cottonwood and willow communities. The western hemlock-yellow cedar series had the fewest species. Alpine and glacier terminus areas probably have a very high number of species, however the crustose lichens, which can predominate in rocky areas, were not comprehensively collected. The low sample number for glacier, alpine and yellow cedar habitats increases the possibility that some frequently occurring lichens have been underestimated, and the converse, that some infrequently occurring lichens have been overestimated.

Lichen flora of western hemlock and shorepine muskeg plant series

There were some consistent similarities and differences between the lichen flora of the two most common plant series. The plant communities of these series are distinctly different, mainly reflecting physical relief differences. Western hemlock plant associations are the climax communities of gradual to steep slopes. Shorepine occurs primarily in flat, wet areas where it is able to survive the strongly acid, low fertility organic soils and poor drainage. It is slow growing and typically the stands are very open. These sites are relatively hotter and sunnier. The following lichen genera or species were found in similar abundance in both: *Alectoria sarmentosa, Bryoria, Sphaerophorus globosus, Cladonia squamosa, C. carneola, C. coniocraea, C. ochrochlora, Platismatia glauca, P. herrei, P. norvegica. Hypogymnia enteromorpha, H. duplicata, H. vittata,* and *Parmelia.*

Lichens of these two vegetation types differed in the following ways:

1. Shorepine species absent from western hemlock stands: *Hypogymnia inactiva, Cladonia maxima, C. uncialis, C. crispata, C. furcata, Bryoria carlottae, B. lanestris, B. oregana,* and *Siphula ceratites*.
2. Western hemlock species absent from shorepine stands: *Lobaria oregana, L. linita,* and *Cladonia transcendens*.
3. Shorepine species uncommon in western hemlock stands: *Cladonia cornuta.*
4. Western hemlock lichens uncommon in shorepine stands: *Peltigera, Nephroma,* and *Usnea.*
5. Species found in both communities but at least twice as common in

a) Shorepine stands: *Cavernularia, Hypogymnia oceanica, Bryoria bicolor, B. cervinula, B. friabilis, Cladonia bellidiflora, C. umbricola* and *Parmeliopsis hyperopta.*
b) Western hemlock stands: *Platismatia lacunosa,* and *Cladonia ochrochlora.*
The most notable difference between these two habitats is the lack of nitrogen-fixing lichens in the shorepine muskegs. All the typical nitrogen fixing genera: *Nephroma, Peltigera, Lobaria, Pannaria, Pseudocyphellaria, Sticta,* are either absent, or uncommon. In fact, this same observation can also be made for alpine areas (discussed below) which are also typically open with water-saturated, acid, histic epipedons as the main substrate.

Lichen flora of Sitka spruce and Sitka spruce-alder plant series from riparian and beach habitats

Lichen communities of spruce stands were most similar to western hemlock stands but *Alectoria sarmentosa, Platismatia norvegica, P. herrei, P. lacunosa* and *Cladonia umbricola*. occurred about half as frequently. In addition, 15-38% of spruce plots had *Cetraria chlorophylla, Pannaria* species, *Lobaria pulmonaria, Hypogymnia physodes* and *Sticta* species, all epiphytic lichens which are absent or uncommon in hemlock or pine plots. The location of spruce stands on edges, e.g. streams, waterways, and beaches, probably accounts for the presence of some of these species. But what combination of light, temperature, humidity and nutrition conditions make these lichens more abundant there is not understood.

Lichen flora of other hardwood riparian communities

Lichen species composition of deciduous hardwood stands was quite distinct. This was expected as bark pH is an important substrate characteristic. Hardwood bark tends to have higher pH. Species diversity was high yet, unlike coniferous forests, there were few species which predominated. For example, while 11 to 15 species were found in the majority of conifer plots, only two species were found in more than half of the hardwood plots. Although *Peltigera* were especially common in all forested areas, *P. britannica, scabrosa, membranacea* and *neopolydactyla* dominated the conifer sites while *P. collina* was the most common *Peltigera* on at hardwood sites. *Cladonia* were found almost universally in all four habitats, however *C. squamosa, C. bellidiflora, C. ochrochlora,* and *C. umbricola*, all common in conifer stands, were either absent or found in less than 10% of hardwood stands sampled. Although 19 different *Cladonia* species were found on hardwood plots, none occurred on as many as 20% of the plots. Other lichens distinctly more common in hardwoods were *Lobaria pulmonaria, L. retigera, L. hallii, L. scrobiculata, Pseudocyphellaria, Cetraria,* and *Sticta.* (all nitrogen-fixing except Cetraria). Species which were highly abundant in the conifers but uncommon or absent in hardwoods were: *Alectoria sarmentosa, Bryoria, Lobaria oregana, Hypogymnia enteromorpha, Sphaerophorus globosus, Platismatia norvegica, P. herrei,* and *P. lacunosa.*

Alpine and Glacier Lichen Communities

These areas also had distinct floras. In alpine areas, *Alectoria nigricans* was the most common macrolichen, followed by *Cetraria subalpina, Cladonia bellidiflora, C. kanewskii, Lobaria linita, Ochrolechia frigida,* and *Pilophorus nigricaulis.* Similarly, the glaciers were typified by a small number of lichens within the genus

Cladonia: C. coccifera, C. cornuta, C. bellidiflora, C. decorticata, C. gracilis, and *C. squamosa* as well as *Parmelia saxatilis*. Typically, the lichens carpet sand, gravels,

Figure 33. Typical lichen species composition and constancy (C) within common vegetation types of the Tongass National Forest. Lichens with <10% constancy are not listed.

Western Hemlock		**Western Hemlock- Yellow Cedar**		**Sitka Spruce**	
Lichen	C	Lichen	C	Lichen	C
Alectoria sarmentosa	97	*Alectoria sarmentosa*	84	*Alectoria sarmentosa*	55
Bryoria glabra	11	*Bryoria trichodes*	17	*Bryoria capillaris*	18
Bryoria trichodes	51	*Cavernularia hultenii*	33	*Bryoria trichodes*	36
Cavernularia hultenii	46	*Cavernularia lophyrea*	33	*Cavernularia hultenii*	36
Cavernularia lophyrea	40	*Cladonia bacilliformis*	17	*Cavernularia lophyrea*	30
Cladonia bellidiflora	49	*Cladonia bellidiflora*	50	*Cladonia bellidiflora*	18
Cladonia coniocraea	20	*Cladonia coniocraea*	17	*Cladonia cornuta*	18
Cladonia cornuta	26	*Cladonia cornuta*	50	*Cladonia fimbriata*	12
Cladonia ochrochlora	31	*Cladonia decorticata*	17	*Cladonia ochrochlora*	15
Cladonia squamosa	63	*Cladonia macroptera*	17	*Cladonia squamosa*	18
Cladonia umbricola	31	*Cladonia maxima*	17	*Cladonia umbricola*	12
Hypogymnia duplicata	71	*Cladonia ochrochlora*	33	*Hypogymnia duplicata*	15
Hypogymnia enteromorpha	89	*Cladina rangiferina*	33	*Hypogymnia enteromorpha*	52
Hypogymnia oceanica	11	*Cladonia scabriuscula*	33	*Hypogymnia vittata*	15
Hypogymnia vittata	34	*Cladonia squamosa*	67	*Lobaria linita*	55
Icmadophila ericetorum	11	*Cladonia sulphurina*	17	*Lobaria oregana*	64
Lobaria linita	57	*Cladonia transcendens*	17	*Lobaria pulmonaria*	24
Lobaria oregana	74	*Hypogymnia duplicata*	84	*Lobaria retigera*	15
Nephroma bellum	20	*Hypogymnia inactiva*	17	*Lobaria scabriuscula*	18
Parmeliopsis hyperopta	11	*Lobaria linita*	50	*Nephroma bellum*	18
Parmelia saxatilis	14	*Lobaria oregana*	50	*Nephroma helveticum*	15
Parmelia sulcata	57	*Mycoblastus sanguinarius*	17	*Nephroma parile*	15
Peltigera britannica	34	*Ochrolechia laevigata*	17	*Parmeliopsis hyperopta*	12
Peltigera membranacea	24	*Parmeliopsis ambigua*	17	*Pannaria laceratula*	12
Peltigera neopolydactyla	48	*Parmelia kerguelensis*	33	*Parmelia saxatilis*	24
Peltigera polydactyla	11	*Parmelia saxatilis*	17	*Parmelia sulcata*	33
Peltigera scabrosa	48	*Parmelia sulcata*	33	*Peltigera britannica*	36
Platismatia glauca	89	*Peltigera britannica*	50	*Peltigera membranacea*	30
Platismatia herrei	61	*Peltigera degenii*	17	*Peltigera neopolydactyla*	12
Platismatia lacunosa	55	*Peltigera leucophlebia*	17	*Peltigera polydactyla*	12
Platismatia norvegica	76	*Peltigera polydactyla*	17	*Peltigera scabrosa*	12
Sphaerophorus globosus	89	*Pertusaria subambigens*	17	*Platismatia glauca*	48
Tuckermannopsis chlorophylla	13	*Platismatia glauca*	67	*Platismatia herrei*	18
Usnea longissima	26	*Platismatia herrei*	33	*Platismatia lacunosa*	15
		Platismatia lacunosa	50	*Platismatia norvegica*	30
		Platismatia norvegica	50	*Pseudocyphellaria anomola*	33
		Sticta sp.	17	*Pseudocyphellaria crocata*	24
		Usnea longissima	17	*Ramalina farinacea*	27
				Ramalina roesleri	12
				Sphaerophorus globosus	55
				Sticta fuliginosa	15
				Sticta weigelii	15
				Tuckermannopsis chlorophylla	12
				Usnea longissima	21
				Usnea sp.	15

Figure 33 (cont.). Typical lichen species composition and constancy (C) within common vegetation types of the Tongass National Forest. Lichens with <10% constancy are not listed.

Sitka Spruce-Alder		**Mixed Conifer**		**Mountain Hemlock**	
Lichen	C	Lichen	C	Lichen	C
Alectoria sarmentosa	20	*Alectoria sarmentosa*	73	*Alectoria sarmentosa*	82
Bryoria capillaris	40	*Bryoria bicolor*	27	*Bryoria bicolor*	27
Bryoria friabilis	13	*Bryoria carlottae*	13	*Bryoria capillaris*	18
Bryoria trichodes	20	*Bryoria lanestris*	20	*Bryoria glabra*	27
Cavernularia hultenii	33	*Bryocaulon pseudosatoanum*	27	*Bryocaulon pseudosatoanum*	27
Cavernularia lophyrea	13	*Bryoria tenuis*	27	*Bryoria tenuis*	45
Cetrelia cetrarioides	33	*Bryoria trichodes*	60	*Bryoria trichodes*	55
Tuckermannopsis chlorophylla	13	*Cavernularia hultenii*	33	*Cavernularia hultenii*	36
Cetraria islandica	13	*Cavernularia lophyrea*	13	*Cetraria islandica*	45
Cladonia bellidiflora	13	*Cladina arbuscula*	13	*Cetraria subalpina*	45
Cladonia coccifera	13	*Cladonia bellidiflora*	60	*Cladonia amaurocraea*	18
Cladonia cornuta	33	*Cladonia cornuta*	33	*Cladina arbuscula*	45
Cladonia fimbriata	20	*Cladonia decorticata*	20	*Cladonia bellidiflora*	91
Cladonia gracilis	13	*Cladonia furcata*	13	*Cladonia coccifera*	45
Cladonia ochrochlora	27	*Cladonia maxima*	20	*Cladonia coniocraea*	36
Cladonia phyllophora	13	*Cladonia ochrochlora*	20	*Cladonia cornuta*	36
Cladonia scabriuscula	13	*Cladina rangiferina*	20	*Cladonia decorticata*	36
Graphis scripta	20	*Cladonia scabriuscula*	20	*Cladonia deformis*	36
Hypogymnia duplicata	13	*Cladonia squamosa*	33	*Cladonia ecmocyna*	18
Hypogymnia oceanica	20	*Cladonia umbricola*	13	*Cladonia fimbriata*	27
Hypogymnia physodes	27	*Cladonia uncialis*	13	*Cladonia gracilis*	45
Hypogymnia tubulosa	20	*Hypogymnia duplicata*	60	*Cladonia maxima*	55
Hypogymnia vittata	40	*Hypogymnia enteromorpha*	47	*Cladonia ochrochlora*	18
Leptogium corniculatum	13	*Hypogymnia physodes*	20	*Cladonia pleurota*	27
Lobaria hallii	13	*Icmadophila ericetorum*	13	*Cladonia pocillum*	18
Lobaria linita	33	*Lobaria linita*	27	*Cladina rangiferina*	55
Lobaria oregana	27	*Lobaria oregana*	27	*Cladonia scabriuscula*	18
Lobaria pulmonaria	27	*cfr. Loxospora undescribed sp.*	13	*Cladonia squamosa*	45
Lobaria scrobiculata	27	*Mycoblastus sanguinarius*	20	*Cladonia sulphurina*	27
Menegazzia terebrata	33	*Parmelia saxatilis*	13	*Cladonia umbricola*	27
Mycoblastus sanguinarius	13	*Parmelia squarrosa*	13	*Hypogymnia duplicata*	36
Nephroma bellum	40	*Peltigera aphthosa*	13	*Hypogymnia enteromorpha*	55
Nephroma helveticum	27	*Pertusaria borealis*	13	*Lobaria linita*	82
Nephroma isidiosum	20	*Peltigera britannica*	40	*Lobaria oregana*	18
Nephroma parile	20	*Peltigera collina*	13	*Nephroma bellum*	27
Nephroma resupinatum	13	*Peltigera membranacea*	20	*Normandina pulchella*	18
Ochrolechia laevigatum	27	*Peltigera neopolydactyla*	20	*Ochrolechia frigida*	18
Parmeliopsis hyperopta	20	*Peltigera polydactyla*	13	*Parmeliopsis hyperopta*	45
Parmelia saxatilis	33	*Platismatia glauca*	53	*Parmelia saxatilis*	18
Parmelia squarrosa	20	*Platismatia herrei*	40	*Parmelia sulcata*	18
Pertusaria borealis	20	*Platismatia lacunosa*	47	*Peltigera aphthosa*	18
Peltigera britannica	27	*Platismatia norvegica*	47	*Peltigera leucophlebia*	27
Peltigera collina	53	*Sphaerophorus globosus*	67	*Peltigera neopolydactyla*	27
Peltigera membranacea	20	*Tuckermannopsis chlorophylla*	20	*Peltigera polydactyla*	45
Pertusaria ophthalmiza	20	*Usnea longissima*	13	*Pilophorus acicularis*	18
Peltigera pacifica	13			*Platismatia glauca*	64
Pertusaria subambigens	20			*Platismatia herrei*	27
Platismatia glauca	33			*Platismatia lacunosa*	18
Platismatia lacunosa	20			*Platismatia norvegica*	36
Platismatia norvegica	47			*Psoroma hypnorum*	18
Pseudocyphellaria anomola	20			*Siphula ceratites*	18
Pseudocyphellaria crocata	27			*Sphaerophorus globosus*	64
Ramalina farinacea	33			*Stereocaulon intermedium*	18
Ramalina inflata	13			*Thamnolia subuliformis*	27
Ramalina thrausta	13			*Umbilicaria hyperborea*	18

Sphaerophorus globosus	33
Sticta fuliginosa	33
Sticta weigelii	13
Tuckermannopsis chlorophylla	20
Usnea ceratina	13
Usnea longissima	13

Table 33 (cont.). Typical lichen species composition and constancy (C) within common vegetation types of the Tongass National Forest. Lichens with <10% constancy are not listed.

Shorepine muskegs		**Cottonwood**		**Willow**	
Lichen	C	Lichen	C	Lichen	C
Alectoria sarmentosa	95	*Alectoria sarmentosa*	14	*Alectoria sarmentosa*	14
Bryoria bicolor	32	*Cavernularia hultenii*	29	*Bryoria bicolor*	14
Bryoria carlottae	24	*Cavernularia lophyrea*	14	*Bryoria fuscescens*	14
Bryoria cervinula	14	*Cetrelia cetrarioides*	14	*Bryoria glabra*	14
Bryoria glabra	21	*Cladonia chlorophaea*	21	*Bryoria trichodes*	14
Bryocaulon pseudosatoanum	37	*Cladonia coniocraea*	14	*Cavernularia hultenii*	14
Bryoria tenuis	26	*Cladonia cornuta*	21	*Cavernularia lophyrea*	14
Bryoria trichodes	71	*Cladonia fimbriata*	29	*Cetrelia cetrarioides*	14
Cavernularia hultenii	60	*Cladonia umbricola*	14	*Tuckermannopsis chlorophylla*	14
Cavernularia lophyrea	23	*Collema furfuraceum*	29	*Cladonia chlorophaea*	14
Cetraria californica	13	*Collema nigrescens*	21	*Cladonia fimbriata*	14
Tuckermannopsis chlorophylla	11	*Dendriscocaulon intricatulum*	21	*Dendriscocaulon intricatulum*	29
Cladonia sp. #2	13	*Heterodermia speciosa*	36	*Hypotrachyna sinuosa*	14
Cladina arbuscula	68	*Hypogymnia enteromorpha*	29	*Hypogymnia vittata*	14
Cladonia bellidiflora	48	*Hypogymnia oceanica*	14	*Leptogium burnetiae*	29
Cladonia cornuta	35	*Hypotrachyna sinuosa*	14	*Leptogium cyanescens*	14
Cladonia crispata	16	*Hypogymnia vittata*	14	*Leptogium furfuraceum*	14
Cladonia decorticata	26	*Leptogium burnetiae*	36	*Leptogium saturninum*	14
Cladonia fimbriata	10	*Leptogium cyanescens*	21	*Lobaria hallii*	57
Cladonia furcata	11	*Leptogium saturninum*	21	*Lobaria linita*	29
Cladonia maxima	45	*Lobaria hallii*	21	*Lobaria oregana*	29
Cladonia pocillum	17	*Lobaria linita*	43	*Lobaria pulmonaria*	43
Cladina rangiferina	75	*Lobaria oregana*	36	*Lobaria scrobiculata*	29
Cladonia squamosa	34	*Lobaria pulmonaria*	71	*Menegazzia terebrata*	14
Cladonia subfurcata	11	*Lobaria scrobiculata*	43	*Nephroma bellum*	43
Cladonia umbricola	18	*Mycoblastus sanguinarius*	21	*Nephroma helveticum*	14
Cladonia uncialis	37	*Nephroma bellum*	50	*Nephroma isidiosum*	29
Hypogymnia duplicata	69	*Nephroma helveticum*	43	*Nephroma parile*	29
Hypogymnia enteromorpha	73	*Nephroma isidiosum*	50	*Nephroma resupinatum*	14
Hypogymnia inactiva	53	*Nephroma parile*	36	*Parmeliopsis hyperopta*	14
Hypogymnia oceanica	48	*Nephroma resupinatum*	36	*Parmelia sulcata*	43
Hypogymnia vittata	27	*Pannaria leucophaea*	14	*Parmeliella triptophylla*	14
Loxospora sp. nov.	19	*Parmelia saxatilis*	29	*Peltigera britannica*	14
Mycoblastus sanguinarius	13	*Parmelia sulcata*	21	*Peltigera collina*	86
Parmeliopsis hyperopta	42	*Peltigera britannica*	14	*Peltigera elisabethae*	14
Parmelia kerguelensis	16	*Peltigera collina*	57	*Peltigera membranacea*	14
Parmelia saxatilis	42	*Peltigera didactyla*	14	*Peltigera scabrosa*	14
Parmelia sulcata	39	*Peltigera membranacea*	29	*Physcia aipolia*	14
Platismatia glauca	84	*Peltigera neopolydactyla*	14	*Platismatia glauca*	14
Platismatia herrei	71	*Peltigera polydactyla*	21	*Platismatia herrei*	14
Platismatia lacunosa	27	*Physcia aipolia*	14	*Platismatia norvegica*	14
Platismatia norvegica	87	*Physconia muscigena*	14	*Pseudocyphellaria crocata*	43
Siphula ceratites	13	*Platismatia glauca*	29	*Psoroma hypnorum*	14
Sphaerophorus globosus	97	*Platismatia norvegica*	21	*Sphaerophorus globosus*	14
Usnea longissima	14	*Pseudocyphellaria anomola*	43	*Stereocaulon coniophyllum*	14
		Pseudocyphellaria anthraspis	14	*Sticta fuliginosa*	29
		Pseudocyphellaria crocata	36	*Sticta wrightii*	29
		Sphaerophorus globosus	14	*Cladonia decorticata*	14

Sticta fuliginosa	36	*Peltigera polydactyla*	29
Sticta wrightii	21	*Pseudocyphellaria anomola*	57
		Pseudocyphellaria anthraspis	14

Figure 33 (cont.) Typical lichen species composition and constancy (C) within common vegetation types of the Tongass National Forest. Lichens with <20% constancy from alpine and glacier termini are not listed . All lichens from the beach/forest ecotone are listed.

Alpine

Lichen	C
Alectoria nigricans	75
Amygdalaria consentiens	38
Bryoria nitidula	25
Cetraria commixta	38
Cetraria ericetorum	25
Cetraria hepatizon	63
Cetraria islandica	38
Cetraria nigricans	25
Cetraria subalpina	63
Cladina arbuscula	25
Cladonia amaurocraea	38
Cladonia bellidiflora	63
Cladonia coccifera	38
Cladonia gracilis	38
Cladonia kanewskii	50
Cladonia macrophyllodes	25
Cladonia maxima	38
Cladonia pleurota	25
Cladonia sulphurina	38
Cladonia uncialis	25
Haematomma lapponicum	25
Lecanora polytropa	50
Lecidoma demissum	25
Lobaria linita	50
Micarea incrassata	38
Nephroma arcticum	25
Ochrolechia frigida	50
Ochrolechia species	25
Parmelia saxatilis	25
Peltigera scabrosa	25
Pilophorus nigricaulis	50
Porpidia thomsonii	25
Pseudoephebe pubescens	50
Rhizocarpon geographicum	25
Solorina crocea	38
Sphaerophorus fragilis	38
Stereocaulon botryosum	38
Stereocaulon arenarium	38
Stereocaulon saxatilis	38
Stereocaulon vesuvianum	25
Thamnolia subuliformis	38
Umbilicaria angulata	25
Umbilicaria hyperborea	25
Umbilicaria proboscidea	25

Glacier termini

Lichen	C
Amygdalaria elegantior	20
Amygdalaria panaeola	40
Buellia papillata	20
Cetraria commixta	20
Cladina arbuscula	40
Cladonia bellidiflora	80
Cladonia cariosa	20
Cladonia carneola	20

Glacier termini

Lichen	C
Cladonia decorticata	60
Cladonia ecmocyna	20
Cladonia fimbriata	20
Cladonia furcata	20
Cladonia gracilis	60
Cladonia metacorallifera	20
Cladonia pleurota	40
Cladonia pyxidata	40
Cladonia squamosa	40
Cladonia subfurcata	20
Cladonia subulata	20
Cladonia symphycarpa	20
Cladonia verruculosa	20
Graphis scripta	20
Haematomma lapponicum	20
Hypogymnia duplicata	20
Lecanora varia	20
Lobaria linita	20
Melanelia sorediata	20
Mycoblastus sanguinarius	20
Neofuscelia subhosseana	20
Ochrolechia frigida	20
Ochrolechia juvenalis	20
Ochrolechia laevigata	20
Parmelia saxatilis	60
Parmeliopsis ambigua	20

Beach /Forest ecotone

Lichen	C
Bryoria tenuis	10
Bryoria trichodes	45
Buellia punctata	5
Buellia spuria	5
Caloplaca exsecuta	5
Caloplaca litoricola	5
Caloplaca citrina	5
Cavernularia hultenii	50
Cavernularia lophyrea	20
Cetrelia cetrarioides	25
Chrysothrix chlorina	5
Cladonia bellidiflora	10
Cladonia cornuta	15
Cladonia ochrochlora	10
Cladonia squamosa	15
Collema fuliginosa	10
Graphis scripta	20
Hypogymnia duplicata	20
Hypogymnia enteromorpha	50
Hypogymnia oceanica	15
Hypogymnia physodes	30
Hypogymnia tubulosa	20
Hypogymnia vittata	25
Hypotrachyna sinuata	35
Leptogium corniculatum	10
Leptogium cyanescens	10

Beach /Forest ecotone

Lichen	C
Lobaria scrobiculata	15
Menegazzia terebrata	10
Menegazzia terebrata	10
Mycoblastus sanguinarius	10
Nephroma bellum	20
Nephroma helveticum	20
Nephroma isidiosum	10
Nephroma parile	30
Ochrolechia arborea	5
Ochrolechia laevigatum	10
Ochrolechia subpallescens	5
Pannaria laceratula	5
Pannaria pezizoides	5
Pannaria saubineti	10
Parmelia hygrophila	10
Parmelia saxatilis	60
Parmelia squarrosa	15
Parmelia sulcata	55
Parmeliopsis hyperopta	10
Parmotrema arnoldii	5
Peltigera aphthosa	10
Peltigera britannica	15
Peltigera collina	45
Peltigera membranacea	40
Pertusaria ophthalmiza	10
Pertusaria subambigens	15
Physcia caesia	10
Platismatia glauca	60
Platismatia herrei	25
Platismatia lacunosa	20
Platismatia norvegica	50
Platismatia norvegica	50
Pseudocyphellaria anomola	25
Pseudocyphellaria anomola	25
Pseudocyphellaria crocata	30
Pseudocyphellaria crocata	30
Psoroma hypnorum	5
Ramalina farinacea	50
Ramalina inflata	10
Ramalina menziesii	10
Ramalina roesleri	25
Ramalina roesleri	25
Ramalina thrausta	20
Ramalina thrausta	20
Rhizocarpon geminatum	5
Rhizocarpon geminatum	5
Rhizocarpon hochstetteri	5
Sphaerophorus globosus	40
Sticta fuliginosa	20
Sticta weigelii	15
Thelotrema lepadinum	5
Tuckermannopsis chlorophylla	40
Usnea ceratina	10
Usnea longissima	40
Xanthoria candelaria	5

Cladonia chlorophaea	20	*Leptogium saturninum*	10	*Xanthoria elegans*	5
Cladonia coccifera	80	*Lobaria linita*	40	*Xanthoria polycarpa*	5
Cladonia coniocraea	20	*Lobaria oregana*	30	*Xanthoria sorediata*	5
Cladonia cornuta	100	*Lobaria pulmonaria*	30		
Cladonia cyanipes	20				

boulders and other mineral substrates, often growing on or among mosses. Nitrogen fixing lichens are absent from the list in **Fig. 32,** but note that various species of *Stereocaulon* (many of which are nitrogen fixing) can often be found in large numbers. Lichen species composition was otherwise quite variable. The variability may be partly an artifact of lumping all alpine habitats together and all glacier terminus habitats together. Plant associations have not yet been developed for early successional and alpine vascular plant communities in southeastern Alaska, so could not be differentiated in this study.

Beach Lichens

Species observed along marine beaches are also listed in **Fig. 33**. The values for constancy are rough estimations since many of the plots were collecting areas and the crustose species were never thoroughly inventoried. The macro-lichens most commonly found on the beach edges were: *Alectoria sarmentosa, Bryoria capillaris, B. trichodes, Cavernularia hultenii, Cetrelia cetrarioides, Hypogymnia enteromorpha, H. physodes, H. vittata, H. tubulosa, Hypotrachyna sinuata, Lobaria linita, L. oregana, Nephroma parile, Parmelia saxatilis, P. sulcata, Peltigera collina, P. membranacea, P. polydactyla, Platismatia glauca, P. herrei, P. norvegica, Pseudocyphellaria anomola, P. crocata, Ramalina farinacea, R. roesleri, R. thrausta, Sphaerophorus globosus, Tuckermannopsis chlorophylla* and *Usnea longissima.*

Of these, *C. cetrarioides, H. physodes, H. tubulosa, H. sinuata, Pseudocyphellaria, Ramalina, T. chlorophylla* and *U. longissima* were common only to marine beaches and riparian areas. The rest were common in most forested habitats. *H. vittata* seems to require open forests and can be found at beach, riparian edges as well as on edges of peat bogs in mixed conifer stands. In more southerly parts of the Pacific Northwest, *Hypogymnia physodes* becomes quite abundant and can be found in many forest types.

3.4 Preliminary assessment of air quality near a point source

The standardized data were plotted in three dimensions: latitude and longitude vs. number of standard deviations from the baseline mean. A three dimensional surface was created using inverse smoothing. The graphs were rotated so that one looks east from a point on the Pacific Ocean toward the community of Sitka (**Fig. 35**). The mill is southeast at the extreme right of the graphs. The end of the road is in the northwest, or the left-hand extreme. The town of Sitka is in the center of each graph (reference **Fig. 34**, a map of the Sitka area and collection locations).

The total number of samples was too low to make conclusive statements about air quality in the Sitka vicinity but the following interpretation could be tested by additional sampling and statistical analysis. Elements

preceded by an asterisk (*) were enhanced at levels characteristic of urban industrial levels according to Nieboer and are also enhanced in comparison to Tongass National Forest baseline values and baseline values from other national parks and forests.

Elements primarily influenced by the mill:

*Sulfur

The major peak in sulfur occurred within 3.2 km of the mill (> 7 standard deviations from the mean) and probably corresponds with fossil fuel combustion. There was a small peak (2 s.d.) at the end of the road which could be explained by boat activity around the state ferry terminal. (97 % of the baseline data fits within two standard deviations).

Phosphorus

Phosphorus was elevated within the vicinity of the mill, gradually returned to baseline at the north end of town and peaked again at the north end of the road.

Calcium and Magnesium

These elements are depressed within the local vicinity of the mill and gradually increase through the town reaching baseline at the north end of town. The single calcium peak at the north end of the road can probably be explained by salt spray. (That particular sample of *L. oregana* was collected from a branch overhanging the beach.) Several collections at the end of the road were also high in magnesium, which is so far unexplained.

Sodium

There was a very sharp peak near the mill (4.5 s.d. from the mean) and another sharp peak (3 s.d.) from the *Lobaria* collected at the north end of the road along the beach, again probably attributable to salt spray. The peak at the mill could be due to the release of sodium from the processing of logs which have been transported in salt water. Otherwise, sodium levels in the Sitka area appeared to be close to baseline values.

*Nickel

Nickel levels around the mill were up to 6 s.d. above the baseline mean and gradually decreased to baseline within the town of Sitka. Levels peaked again around the ferry terminal vicinity at about 2 s.d. above the mean. Combustion of heavier fuel types by the mill and by boats docking at the terminal could explain these peaks.

Copper

Copper was strongly elevated in the vicinity of APC (up to 5 s.d. above the baseline mean at the Thimbleberry Lake trailhead) and gradually decreased to baseline through Sitka and peaks to 3 s.d. again in the ferry terminal vicinity.

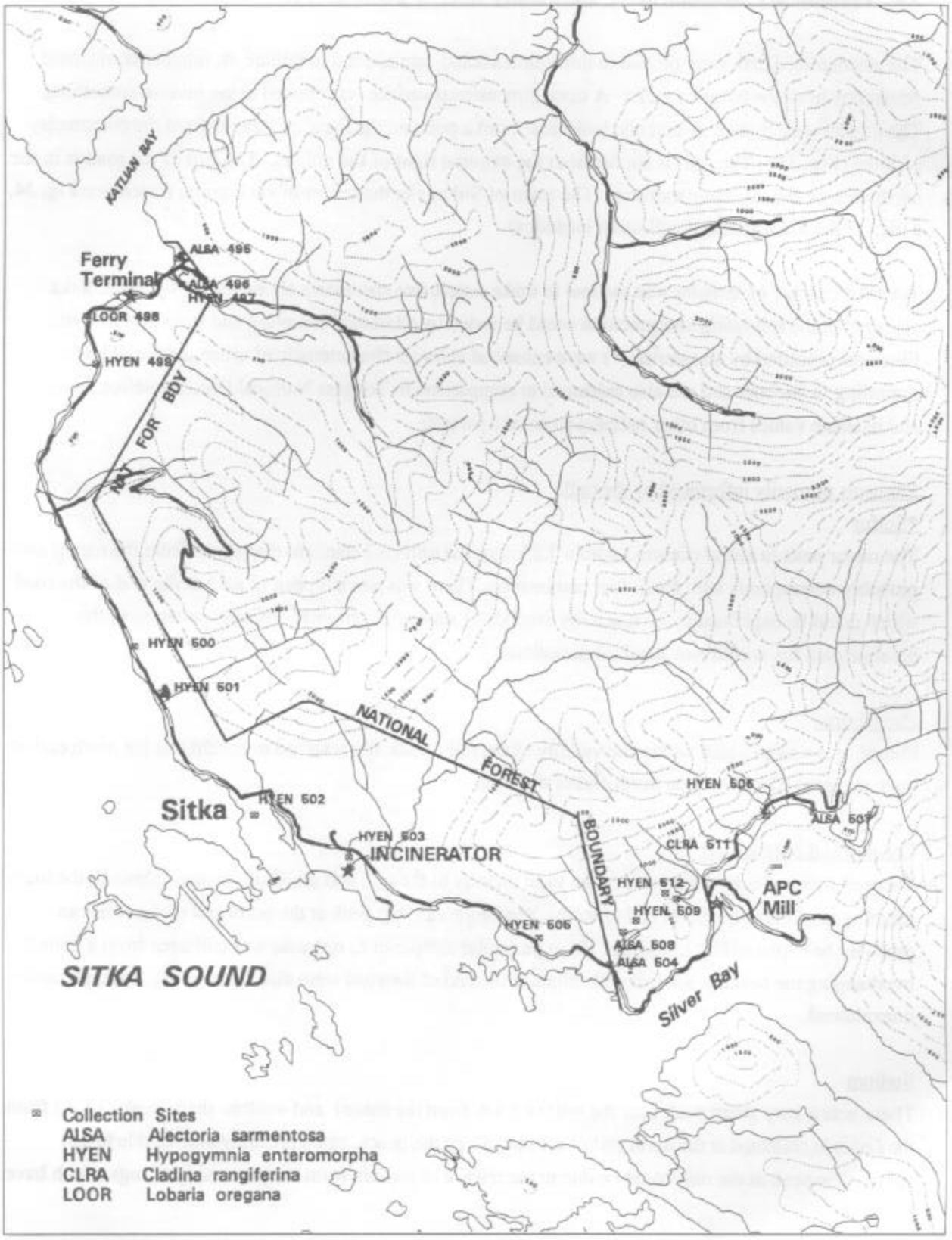


Figure 34. Lichen tissue collection sites in the vicinity of Sitka, Alaska.

Manganese

Manganese concentrations did not appear to be much different from baseline values anywhere in the Sitka area though all were slightly depressed (-0.2 to -1.1 s.d. from the mean). Highest values occurred around the mill and at the end of the road.

Cadmium

Cadmium was highest in the vicinity of the mill (up to 5 s.d. above the mean), peaked again around the town incinerator and otherwise did not appear to be significantly different from baseline values.

Elements primarily influenced by the town of Sitka and roads:

Potassium:

Potassium was generally slightly elevated throughout the Sitka area. Uptake and efflux of potassium is variable in lichens exposed to varying amounts of SO_2 and heavy metals and it is difficult to attribute the distribution of this element to any simple source or cause. All except one measurement were less than 2 s.d. from the mean.

*Zinc

Highest zinc concentrations occurred in the city of Sitka itself (3.5 s.d.) peaking at the collection site closest to the city incinerator, and also in the vicinity of the mill (3 s.d). The source of the zinc is unclear as most zinc in the atmosphere arises from base metal and voltaic-cell industries (Gough, 1992).

*Chromium

Highest levels of chromium (up to 4 s.d.) were centered around the city of Sitka and the ferry terminal (4 s.d.). Elevated chromium levels can be associated with automobile exhaust.

Aluminum and *Iron

Aluminum and iron concentrations peaked in town and at the north and south ends of the road. These elements are mineralogically abundant and usually associated with road dust. The peaks in town may correspond with areas of heaviest road activity . The north and south peaks may correspond with unpaved road sections.

Boron

Boron is elevated throughout the Sitka area with very high peaks around the mill (up to 8 s.d. above the baseline mean) and peaks up to 6 s.d. in the vicinity of the ferry terminal.

Figure 35. Three dimensional presentation of elemental analysis of lichen tissue around the community of Sitka in 1990. (The center of each graph is the city of Sitka, the left extreme is the ferry terminal and north road end, the right extreme is the Alaska Pulp Corporation mill vicinity)

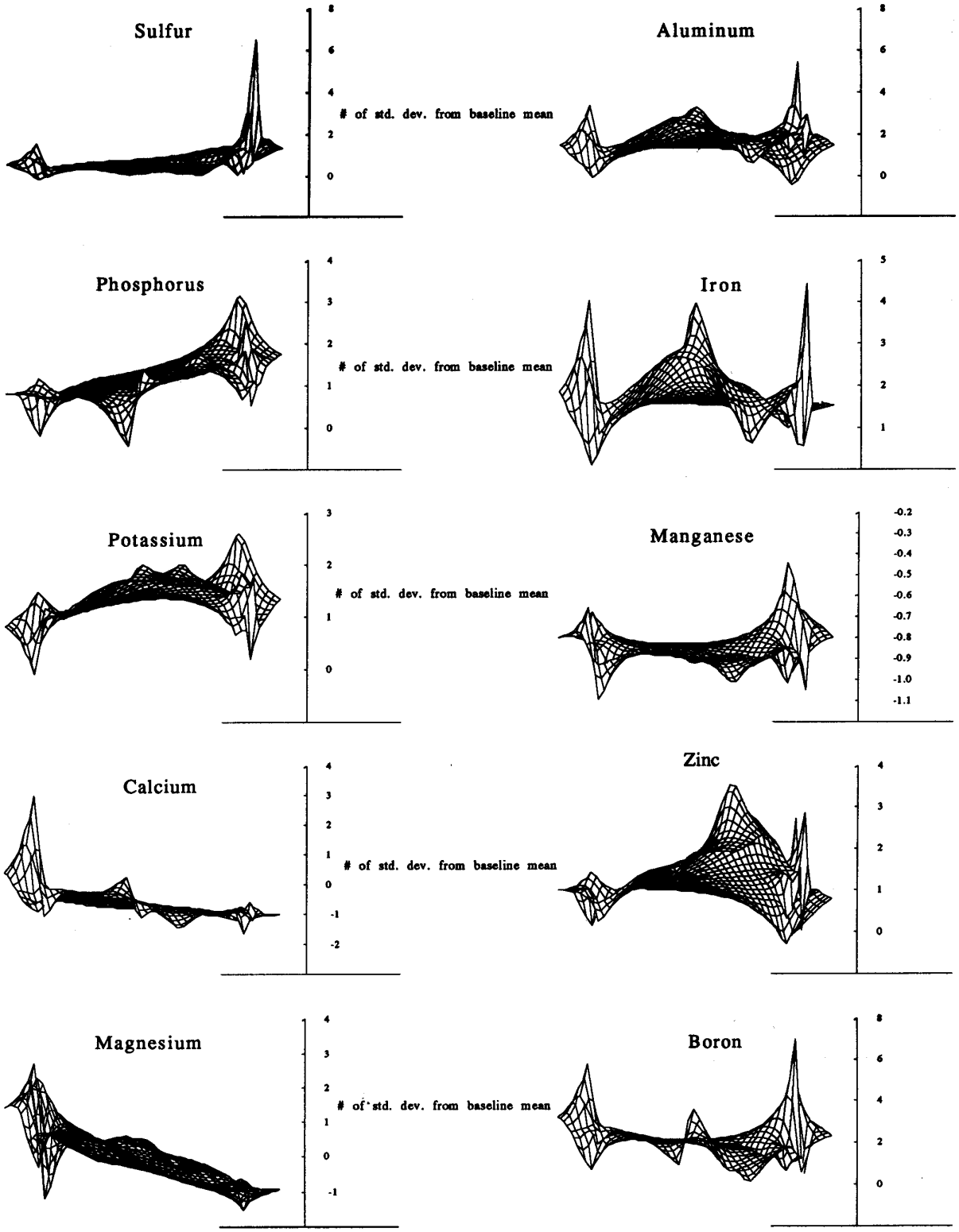
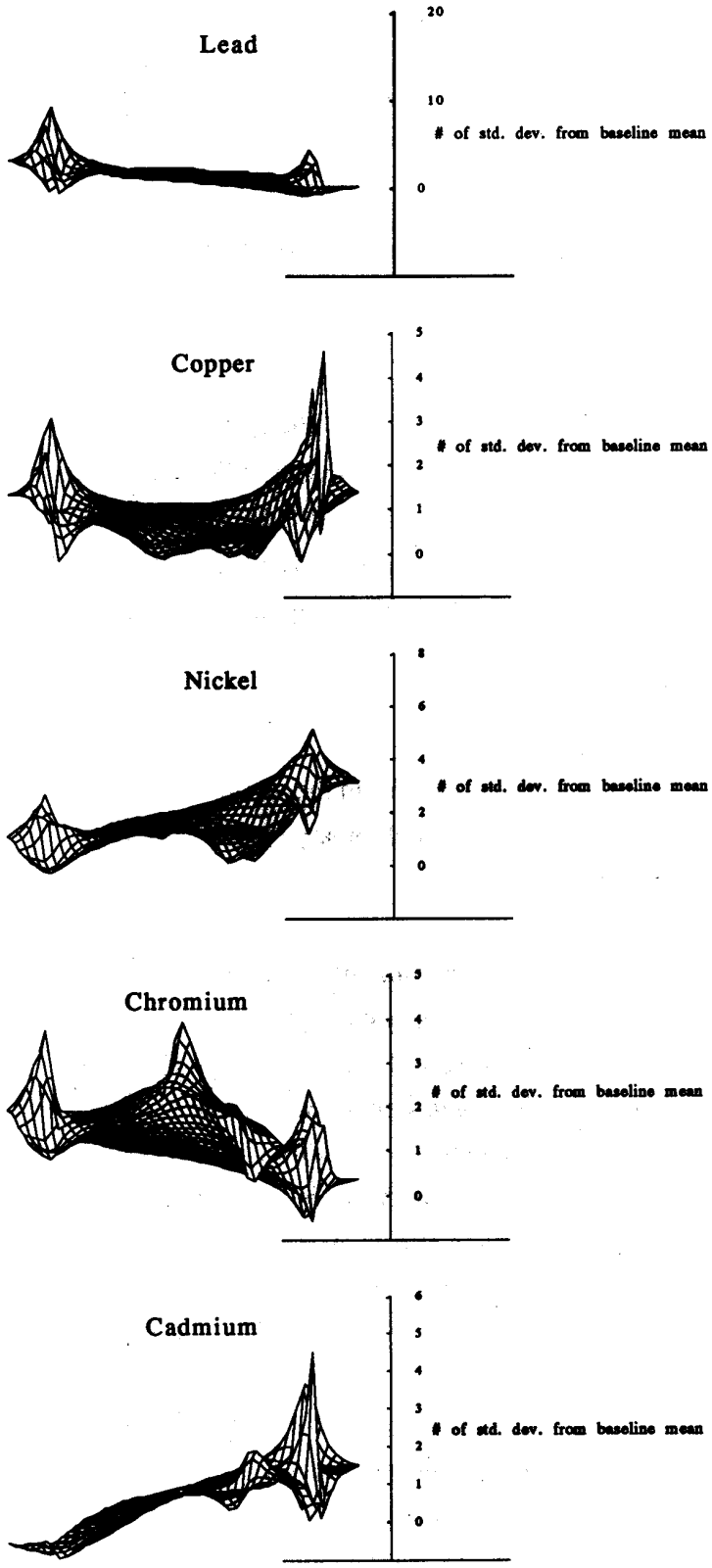


Figure 35 (cont.)



*Lead

Lead levels were elevated throughout the Sitka area. An extremely high peak of about 10 s.d., i.e. tissue concentrations more than fifty times the baseline mean, was observed at the north end of the road in the vicinity of the ferry terminal. A smaller peak (4 s.d.) occurred at 3 miles from APC. Most of the data could be explained as a road effect as all collections made off the roads were low. The exception to this is the *Lobaria* collected on the beach near the ferry terminal. Lead was a former component of gasoline and is still a component of fuel oil containing recycled motor oil.

Elements also influenced by activities at the north end of the road:

The elevation of S, Mn, Cu, Pb, Ni, Mg, and Cr at the end of the road and/or in the vicinity of the ferry terminal was unexpected. More information is needed to confirm these preliminary results and assess any impacts. Of these seven elements, lead may be of greatest concern.

In a comparison to literature values (see **Fig. 18**), elemental analyses around the Sitka area indicated that S, Ca, Mg, Fe, Mn, Zn, Pb, Ni, and Cr may be enhanced to levels generally characteristic of heavily industrialized areas (Nieboer & Richardson, 1981). As noted previously, Tongass National Forest baseline values for Ca, Mg, Zn, and Mn, especially in *H. enteromorpha*, were already in the enhanced range and are possibly a reflection of the maritime climate. Although Sitka values for calcium were enhanced according to Nieboer & Richardson (1981), they averaged about 50% less than baseline values for the Forest. High calcium levels can protect lichens from damaging effects of SO_x (Nieboer & Kershaw, 1983). The reduction of calcium could be an indication of stress in these lichens and/or a result of leaching due to acid rain.

A survey of changes in the lichen community along the Sitka road system made a visually dramatic impact. Within 0.8 km of the mill, most trees were completely bare of lichens although a faint, white, non-reproductive crustose species was present in some cases. The trunks were a glossy brown color. By 1.6 km from the mill, at least two crustose species were present, one with apothecia (reproductive bodies). The first macrolichens, *Hypogymnia enteromorpha* and *Platismatia norvegica*, were observed at 2.4 km along Blue Lake Road and at 4.8 km along the Sawmill Creek Highway. Another macrolichen, *Parmelia sulcata*, was first observed at 3.2 km along Blue Lake Road and at 6.2 km along Sawmill Creek Highway. The number of crustose lichens also increased with distance from the mill . Near the city center, lichens covered approximately 50% of the surface of the alders, and appeared healthy. This percentage generally continued to rise until by 21.5 km the trees were almost completely encrusted in lichens, giving the bark a white appearance. Mosses first began appearing on alder trunks at 17.6 km and were common by 21.5 km.

It was not possible from this preliminary investigation to determine the relative influence the road or the city of Sitka had on population of alder trunks by lichens. Casual observations away from the road along the Heart Lake and Thimbleberry Lake national forest trails (about 0.8-1.6 km from the mill) indicated that the epiphytic lichen flora was very sparse, though enough *H. enteromorpha* was found for tissue analysis. In contrast, trees

along the Indian River foot trail in the next valley north, only about 2.4 km from the mill, were well covered. To separate effects of the road and various emission sources from each other, more measurements are needed.

4. RECOMMENDATIONS FOR CONTINUED MONITORING

4.1 Detection of Forest-wide air quality changes

4.11 Remeasurements of permanent plots

To assess regional changes in air quality, permanent plots should be periodically remeasured using the same sampling methodology and target species described in this report. Remeasurements could be made every five years over one or two summers of intensive field work, or on a less intensive yearly basis remeasuring each plot once every five years. In either case the work could be done by a single crew with taxonomic expertise or by many crews from the various Areas/Ranger Districts after training by a program coordinator with taxonomic expertise. Future monitoring efforts should address 1), natural temporal variability of element concentrations in the four lichen species and 2), detection limit problems for cadmium, chromium, nickel and lead.

4.12 Continued inventory of underinvestigated habitats and the crustose flora

Adequate inventory information is essential for good ecosystem management and inventory information collected for air quality monitoring purposes can have many other uses. While in the field it is relatively easy to continue the lichen inventory. The following habitats are poorly inventoried:

a. Freshwater and marine habitats. These areas are usually the transportation drop off points and would not cause additional field expense. Aquatic lichens and bryophytes indicators could be developed to aid water quality monitoring efforts.

b. Alpine and subalpine areas. In other parts of the country, alpine and subalpine areas have shown considerably more sensitivity to air quality changes. Our tissue analysis information from Crystal Mountain indicates the baseline values may be slightly different from low elevation sites. Ecological data on alpine vascular vegetation as well as the lichens is also needed, particularly in designated Wildernesses to establish benchmarks of current conditions.

c. Unusual habitats, e.g. areas with unusual mineralogy such as serpentine or limestone outcroppings with Karst topography, or geothermal areas and hot springs. These areas have very high potential as habitats for rare or unusual species.

d. Managed vs. natural areas, to look at effects of timber harvest on non-vascular community ecology, succession and mineral cycling. Comparisons of different successional stages would aid the development of indicators of old-growth and/or biologically diverse forested stands.

e. Crustose lichens are an important component of the lichen flora, perhaps half the species richness, and certain groups, such as the order Caliciales are useful indicators of forest stability and habitat continuity (Tibell, 1991). Future inventory efforts should focus on improving the inventory and ecological understanding of these species.

Non-vascular plant information should be added to the geographical information system database to make the data readily accessible for environmental impact assessments (especially for threatened and endangered species), other monitoring efforts, or ecological studies .

4.13 Assess sensitivity of lichens to the criteria pollutants

To link changes in lichen communities with changes in atmospheric levels of sulfur dioxide, nitrogen oxides and ozone, some assessment of the sensitivity of key lichen species is needed. Due to the very humid, mild climate in Southeast Alaska, the lichens are metabolically active much of the year and may therefore be unusually sensitive to air pollution. This has several implications:

1. If literature values correlating presence/absence data with atmospheric concentrations are from areas where lichens are frequently metabolically inactive, using these values could overestimate air pollution problems in Southeast Alaska.
2. The standards for SO_2, based on protection of human health, may allow pollutant levels which are too high to protect all vegetation.

Laboratory fumigation can assess the air pollution sensitivity of the four target lichens by determining atmospheric levels of SO_2, ozone and nitrous oxides which cause detrimental effects to these lichens. The Stikine Area has contracted Arizona State University to provide laboratory assessments of SO_2 sensitivity for *A. sarmentosa*, *C. rangiferina*, *H. enteromorpha* and *L. oregana*.

Field observations are needed to establish relative sensitivities of common lichens and to confirm laboratory data and literature reports. An unusual opportunity exists to monitor the lichen communities at the two largest stationary point sources of sulfur emissions, the Sitka and Ketchikan pulp mills, one of which is in operation and the other which has recently closed. The sensitivity of most of the common lichens of the Tongass National Forest could be assessed on a relative scale, similar to the study cited in the inventory list of this report.

4.14. Community analyses of branch epiphytes

Permanent plot branch epiphytes could be remeasured, depending on the results of the community analysis of the shorepine plots.

4.2 Assessment of point source impacts

4.21 Mendenhall Valley area

The Alaska Dept. of Environmental Conservation has developed State Implementation Plans for reducing airborne particulate matter levels in the Mendenhall Valley. As much as half the non-attainment area is on National Forest land and therefore the Forest Service has an interest in participating in this process. For example, lichens could be used to monitor dust levels by measuring aluminum and iron content or aluminum/titanium ratios. Tissue analyses could be used immediately to identify and map the problem areas and establish present conditions. As attainment procedures are applied, remeasurements of lichen aluminum, iron, and/or titanium levels could be made to monitor air quality improvements.

4.22 Pulp Mills

Sulfur Dioxide

Controversy about SO_2 emissions and impacts of total emissions on vegetation from the Ketchikan pulp mill remains. Lichen tissue and community analysis could be used to help validate existing SO_2 modeling.

Chlorinated compounds

From the perspective of forest and human health, the possible contamination of the air with an unknown array of chlorinated hydrocarbons may be a much more serious concern than the sulfur dioxide effects-- which from this preliminary work, seem to be limited to the immediate vicinity of at least one of the mills. Chlorinated organic compounds concentrate in upper levels of food chains, especially fat-based food chains, and can be toxic at exceedingly small tissue concentrations, depending upon the compound(s). The most serious known compounds (dioxins, furans and PCBs) are now being contained in a solidified form in the Sitka city landfill (Baumgartner, 1994). However, neither the actual content of the airborne emissions nor their deposition pattern is well understood. Direct analysis of these substances is quite expensive but there may be some potential to develop an AOX (total adsorbable halides) test to map the deposition area of chlorinated organic compounds in the same manner as SO_2 deposition. Lichens or mosses would be a suitable terrestrial indicator because of their ability to absorb and concentrate airborne pollutants. Tissue analysis could be used to delimit areas of concern.

4.23 Green's Creek

Kennecott Green's Creek Mining Company on Admiralty Island was planning a facility expansion which could require instrumented monitoring of SO_2 and NO_x. Although immediate expansion is unlikely, this could be the first opportunity in southeast Alaska to obtain background atmospheric concentrations of SO_2 and NO_x. It would be appropriate to collect and analyze lichens from the vicinity of the monitors to calibrate tissue S and N levels with ambient SO_2 and NO_x levels. Once the expansion is operational, additional calibration points could be obtained.

4.24 Molybdenum mine

If molybdenum mining is approved within the Misty Fjords National Monument, it would be important to gather baseline air quality data from that area before and after construction/operation to understand the extent and severity of any impacts from the mine on air quality in the Monument .

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6. Appendices

6.1 Lichens of the Tongass National Forest: sulfur dioxide sensitivity and distribution.

6.2 Plot locations and descriptions.

6.3 1989-1991 Elemental analysis data.